The DarkSide Program

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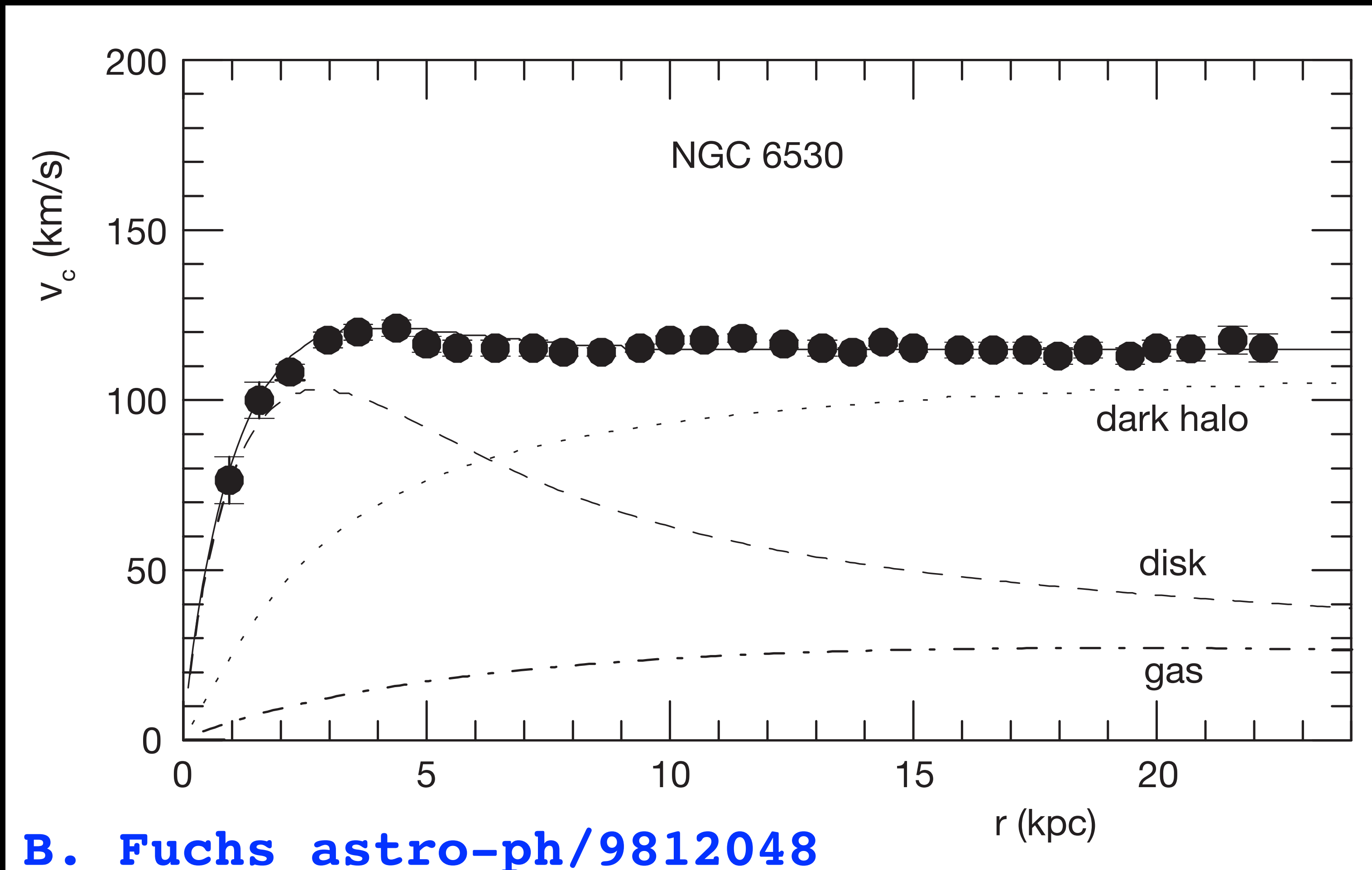
IHEP
Beijing, PRC

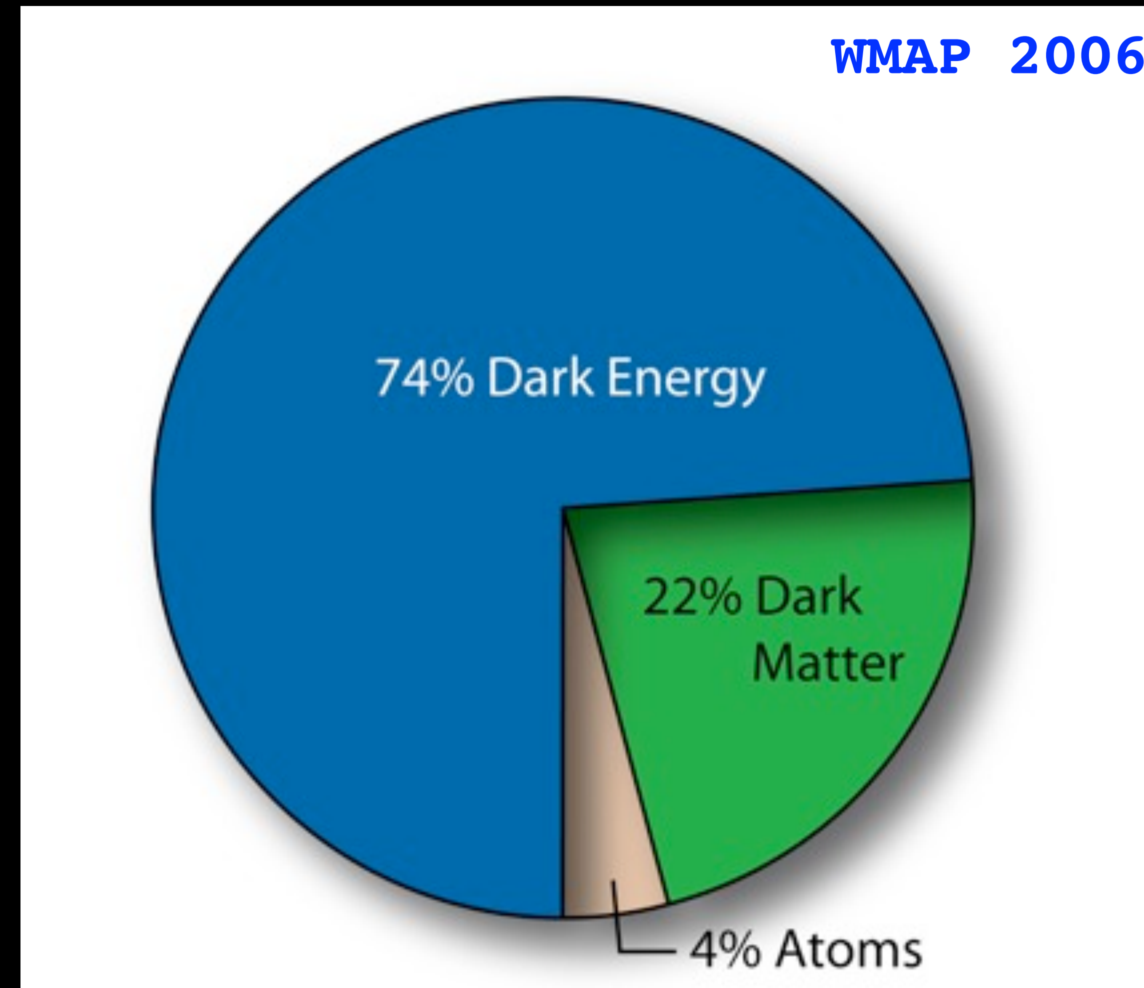
Image Credit: Fermilab

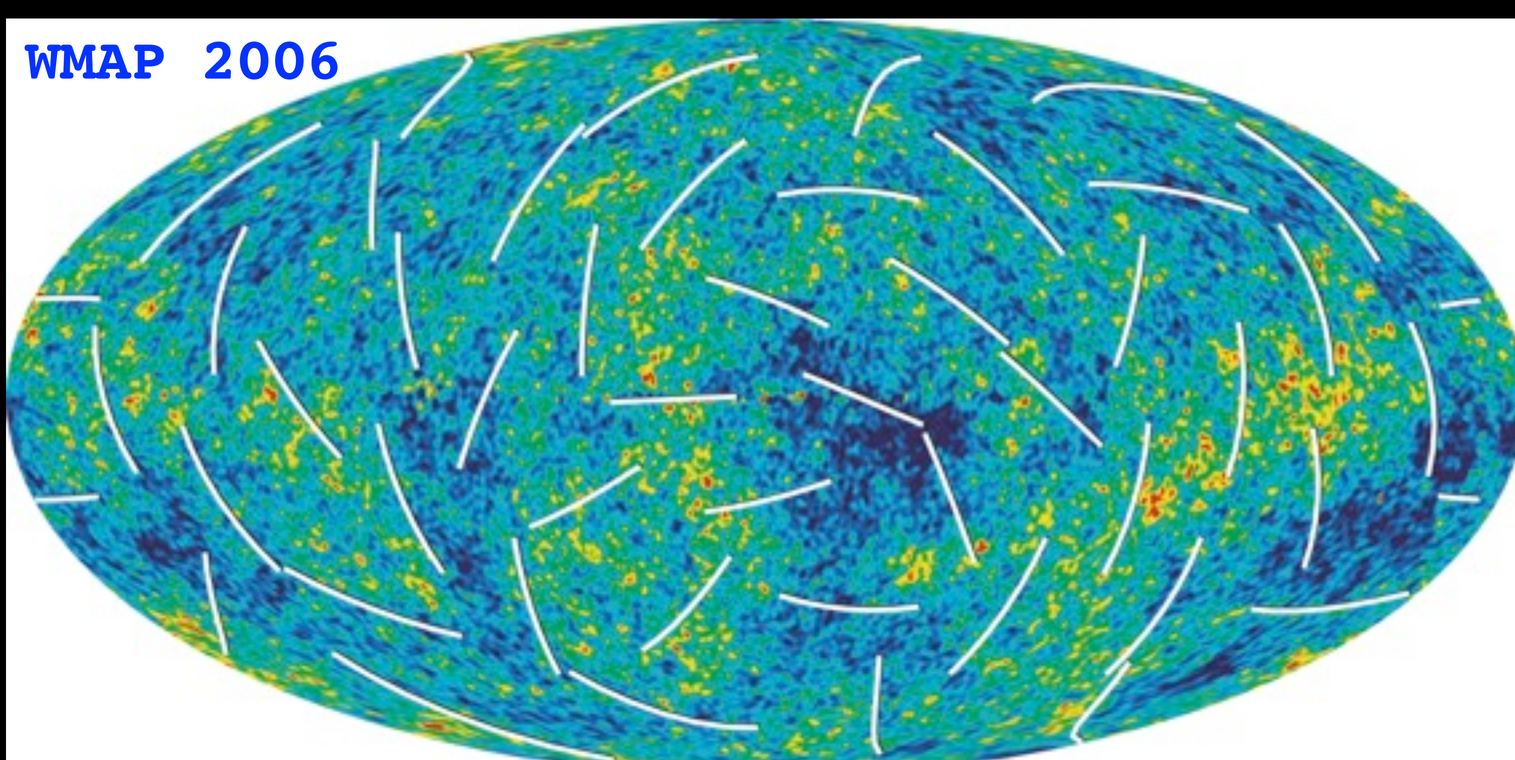
DarkSide

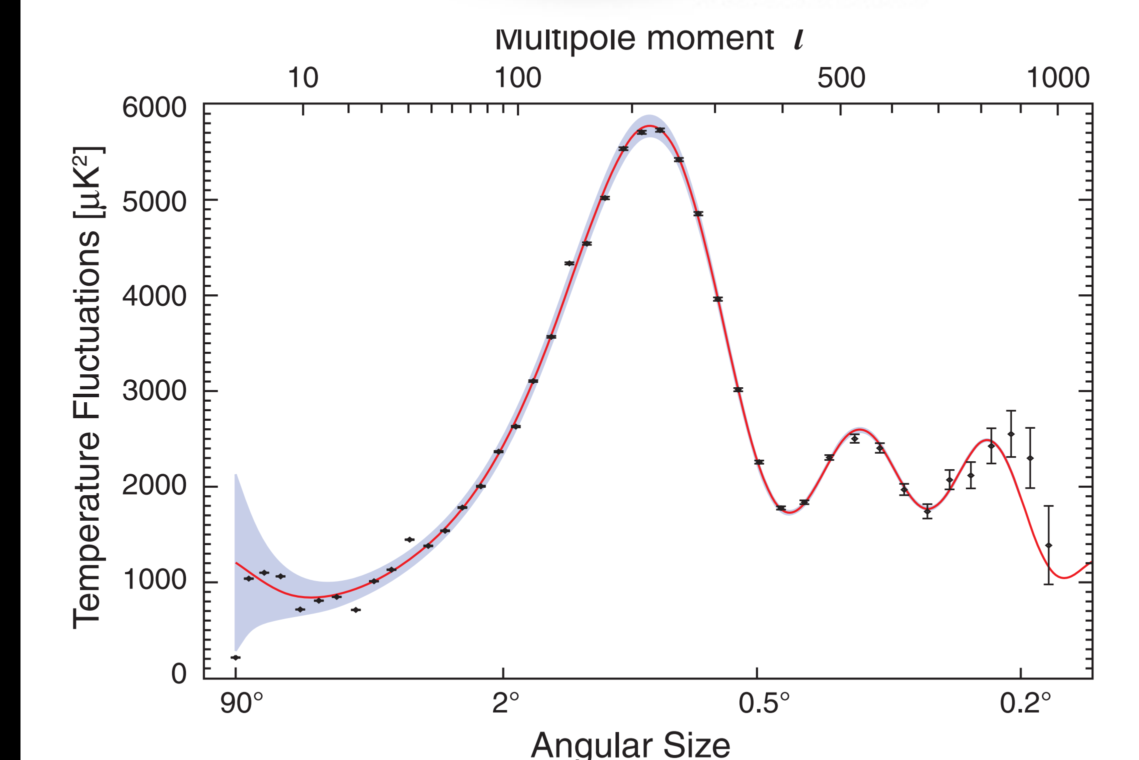
Augustana College – SD, USA
Black Hills State University – SD, USA
Fermilab – Il, USA
IHEP – Beijing, China
INFN Laboratori Nazionali del Gran Sasso – Assergi, Italy
INFN and Università degli Studi Genova, Italy
INFN and Università degli Studi Milano, Italy
INFN and Università degli Studi Napoli, Italy
INFN and Università degli Studi Perugia, Italy
Joint Institute for Nuclear Research – Dubna, Russia
Princeton University, USA
RRC Kurchatov Institute – Moscow, Russia
St. Petersburg Nuclear Physics Institute – Gatchina, Russia
Temple University – PA, USA
University of California, Los Angeles, USA
University of Houston, USA
University of Massachusetts at Amherst, USA

Dark Matter Evidence



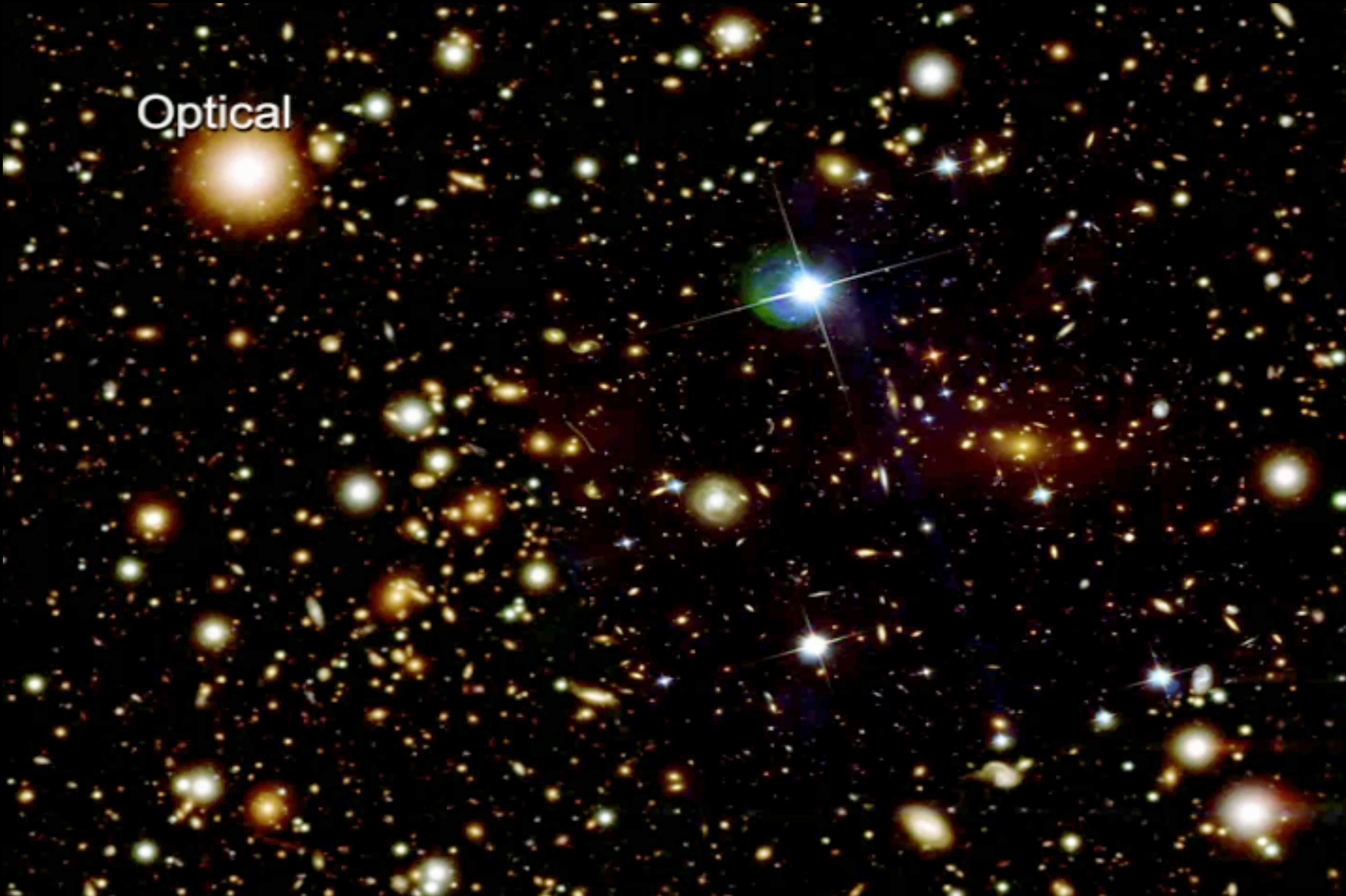






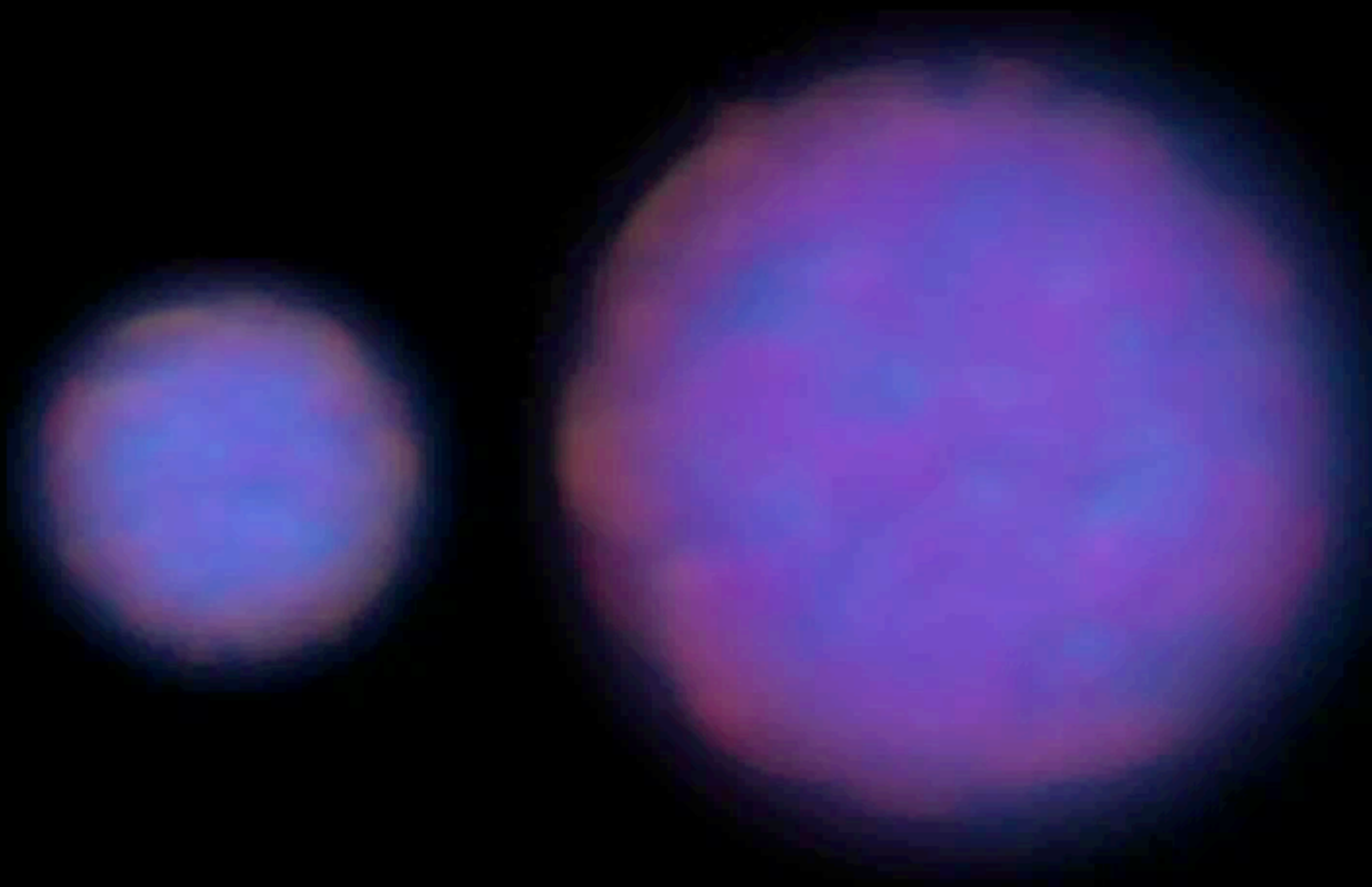
Bullet Cluster

NASA



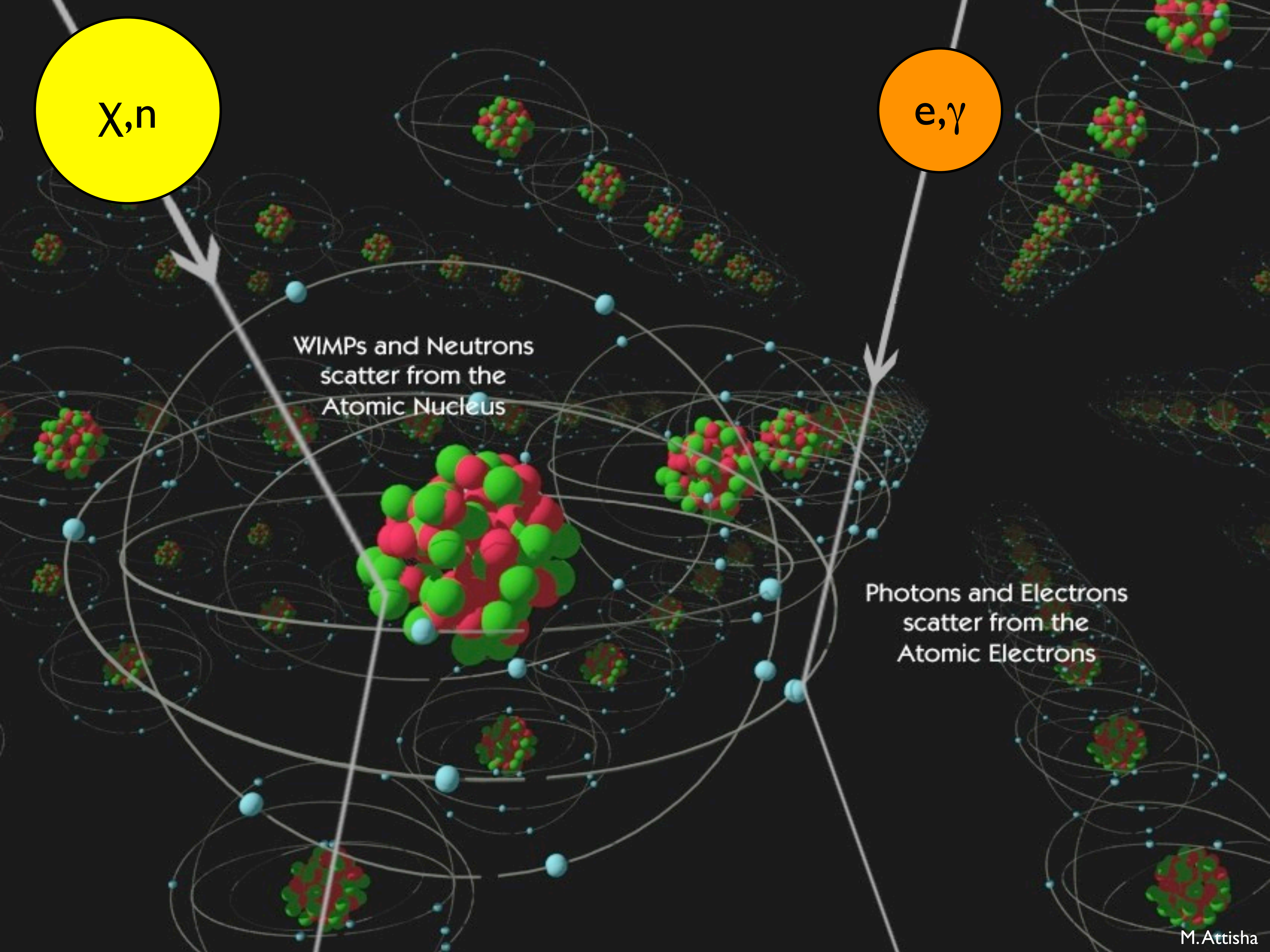
Bullet Cluster

NASA



Dark Matter

- Best evidence for new physics beyond Standard Model
  - Unambiguous evidence
  - Possibly connected with electroweak symmetry breaking, SUSY, and structure formation
- Very bright prospects for experimental observation
  - Astroparticle physics: direct and indirect searches
  - Particle physics: CMS and ATLAS at LHC
  - Cosmology: halo profiles, CMB, BBN


χ,n
e,γ
WIMPs and Neutrons scatter from the Atomic Nucleus
Photons and Electrons scatter from the Atomic Electrons
M. Attisha

Direct Detection Requirements

- Low energy nuclear recoils (< 100 keV)
- Low rate (~1 event/ton/yr for 10^{-47} cm^2)
- Background, background, background
- Detector designed for "Discovery"

New Technologies

- Germanium crystals (CDMS iZips, Edelweiss)
- Bubble chamber (COUPP, PICASSO)
- Xenon
  - 1-Ph: XMASS
  - 2-Ph:LUX, XENON
- Argon
  - 1-Ph:DEAP,CLEAN
  - 2-Ph: DarkSide, WARP, ArDM

Elements for a “Discovery” Detector

- Low threshold energy (few keV)
- Large mass for high sensitivity (>1 ton)
- Low Background (<<1event/ton/year)
- Background measurable in situ by design

CDMS

- Rejection of beta/gamma events by two signals: ionization and energy (phonons)
- Rejection factor of bulk electron events: $\sim 10^6$
- Rejection factor for surface electrons (210Pb) improved significantly with iZIP detectors: $\sim 10^4$?
- Passive shielding for neutrons with present plan; no in-situ measurement of background

COUPP

- Bubble chamber with ionization threshold tuned to reject beta/gamma events. Visual counting of bubbles. Rejection factor: ~10^{10}
- Alpha decay produces bubbles and may be dominant background. U and Th purity levels of 10^{-16} g/g will achieve limits of few events/ton/day. Difficult, but achieved by Borexino. Not yet for COUPP?
- Alpha particles produce bubbles with a louder acoustic signal. Acoustic discrimination can overcome U/Th impurities and is crucial for high sensitivity. Under investigation.
- Passive shielding for neutrons with present plan; no in-situ measurement of background

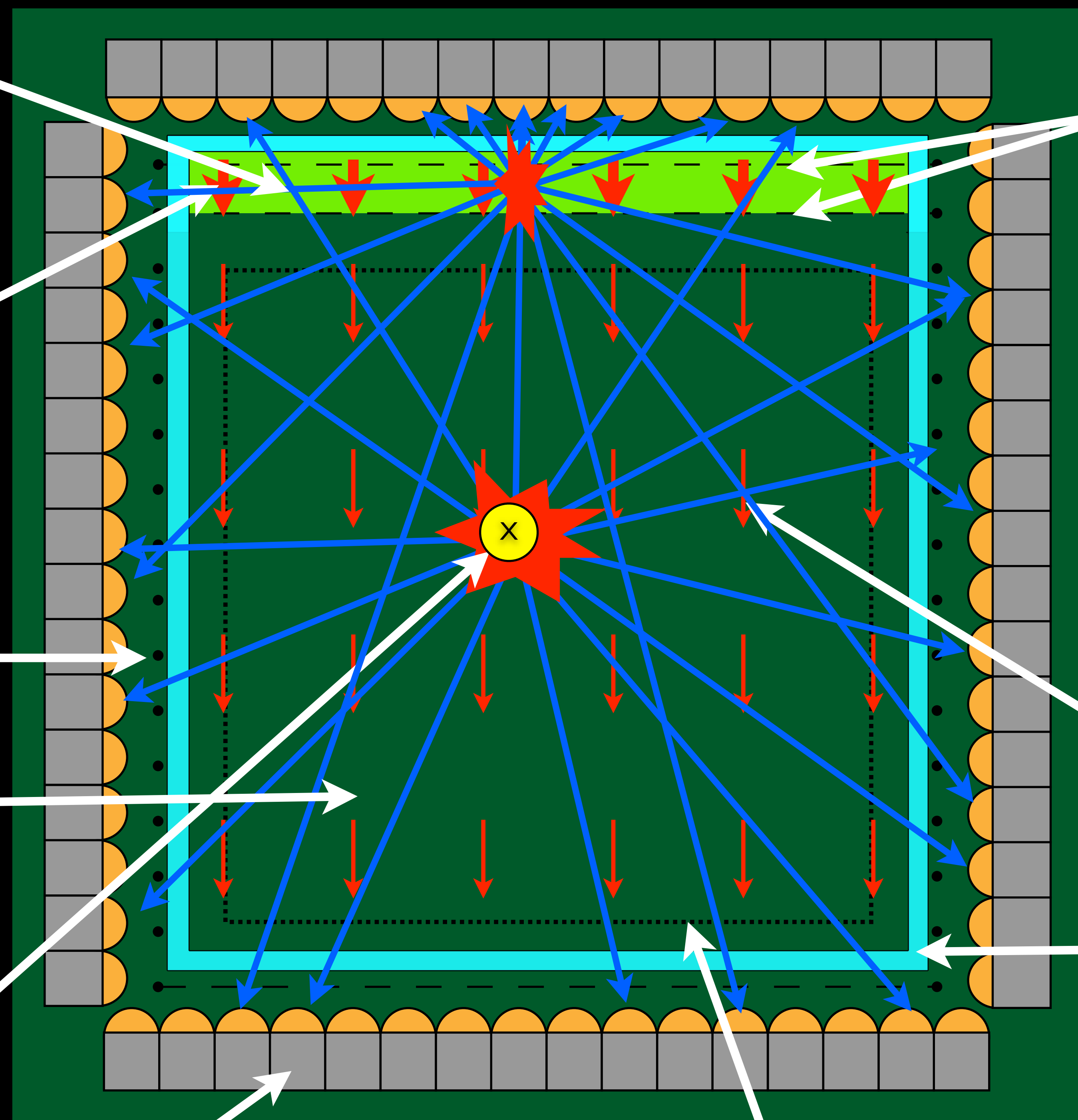
XENON

- LUX and XENON operate in 2-phase mode with single scintillation/ionization discrimination to reject beta/gamma events. Rejection factor of 200 achieved, 1000 seem possible with Zeplin-III design (High E-field).
- Self-shielding effective to reduce external gamma background, but at a cost of xenon for shielding.
- Vulnerable to internal beta activity.
- Lacks multiple discrimination.
- Passive shielding for neutrons with present plan; no in-situ measurement of background.

DarkSide-50: a "Discovery" Experiment

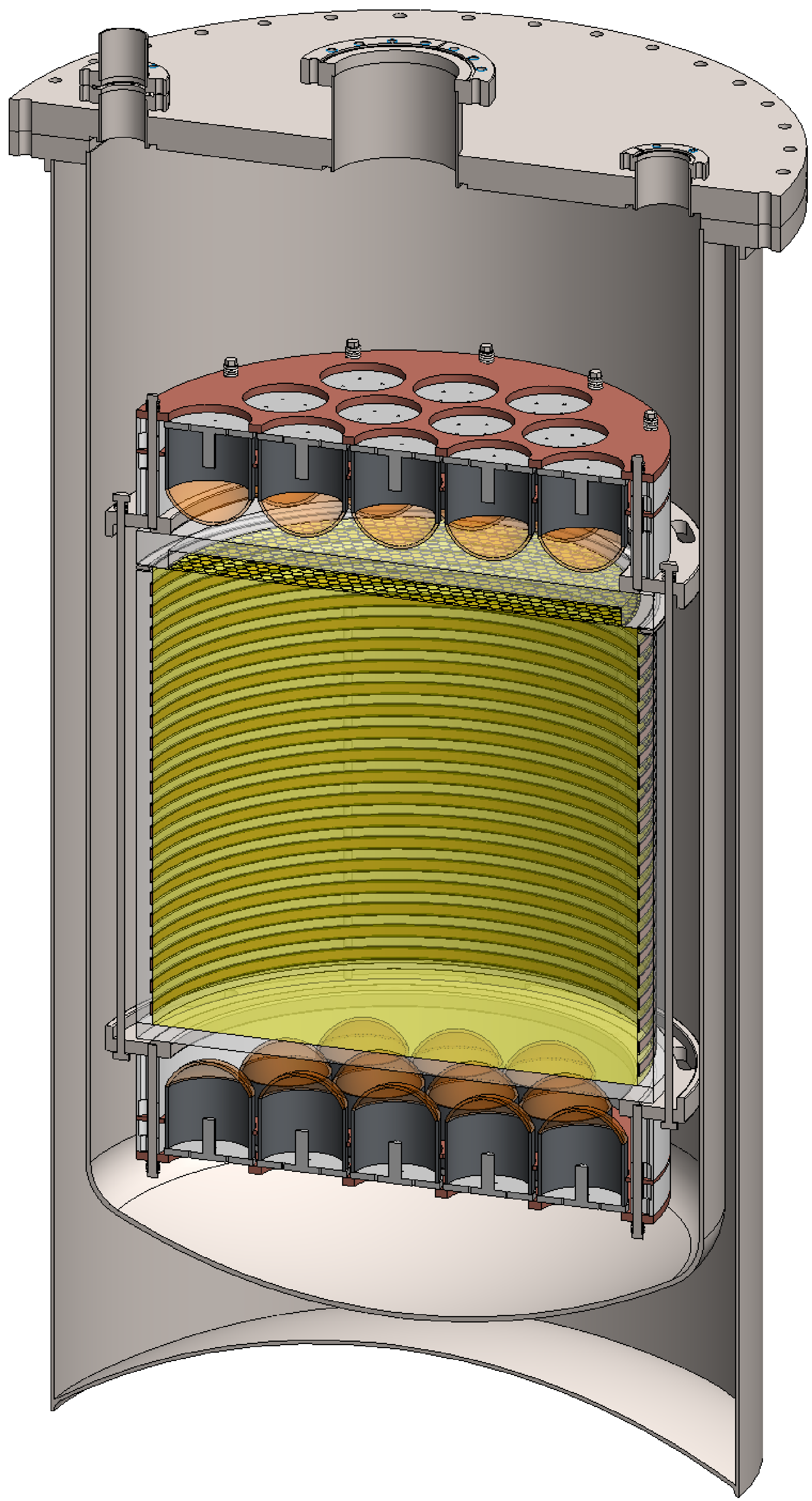
- DarkSide-50 with neutron veto in CTF will have the ability to demonstrate extremely low backgrounds:
  - <0.1 ev / 0.1 ton-yr
- Make credible detection claim possible with the observation of a few events
- Allow direct demonstration that background-free operation of ton-scale detector is possible

TPC in Action



Discrimination in Argon

- LAr is one of the brightest scintillators known. Pulse shape of primary scintillation provides very powerful discrimination for NR vs. EM events:
  Rejection factor exceeds 10^8 for > 60 photoelectrons (Boulay & Hime 2004; Benetti et al. (WARP) 2006)
- Ionization drift is well established technology on very large scale detector. Ionization:scintillation ratio is a strong and semi-independent discrimination mechanism:
  Rejection factor ~10^2 (Benetti et al. (ICARUS) 1993; Benetti et al. (WARP) 2006)
- Spatial resolution from ionization drift localizes events, allowing rejection of multiple interactions, "wall events", etc.
- Two-phase LAr-TPC combines these characteristics into a powerful detection technique, as established by WARP



Neutron Veto

- Our approach (F. Calaprice): rely on (n,α) on ^{10}B
- Alpha particle extremely low range
- Alpha particle can be observed using borated liquid scintillator ... remember BOREX?
- 99.8% efficiency for radiogenic neutrons with ~1 m thick shield
- Many 9's of efficiency possible with thicker shields for radiogenic neutrons not captured within detector

Benefits of BX integration to DarkSide

- Integration of water and scintillator purification plants (distillation column, counter-current water extraction column, stripping column)
- Availability of second purification plant under construction by Princeton University for purification of scintillator fluors
- Unique expertise of Borexino collaboration in handling of scintillators and low background techniques

Why is depleted argon from underground so crucial?

- Radioactive ^{39}Ar produced by cosmic rays in atmosphere
  - beta decays, $Q = 565$ keV, $t_{1/2} = 269$ years
- In atmospheric argon:
  - $^{39}Ar/Ar$ ratio 8×10^{-16}
  - specific activity 1 Bq/kq
- Limits size (and sensitivity) of argon detectors to 500-1000 kg due to ^{39}Ar events pile-up

Why is underground argon desirable?

- ^{39}Ar-depleted argon available via centrifugation or thermal diffusion, but expensive at the ton scale!

- ^{39}Ar production by cosmic rays strongly suppressed underground

- Motivated by success in Borexino
  - Low background from ^{14}C crucial for observation of low energy neutrinos with organic liquid scintillators.
  - Hydrocarbons in deep underground reservoirs results in low cosmogenic ^{14}C

Counter for Underground DAr Measurement

^{39}Ar Counter Design

Passive Shielding:

2” OFHC Copper

8” Lead Shielding (^{210}Pb ~65Bq/kg)

Active Shielding:

2” Plastic Scintillator Veto, ~2PI S.A Coverage

Background in (100,600)keV: ~0.3Bq at sea level

Original Setup:

Ar mass: LAr ~1kg

WLS: TPB

PMT R6233-100

25” Acrylic Light Guide

Lose 50% Light

Upgrading…

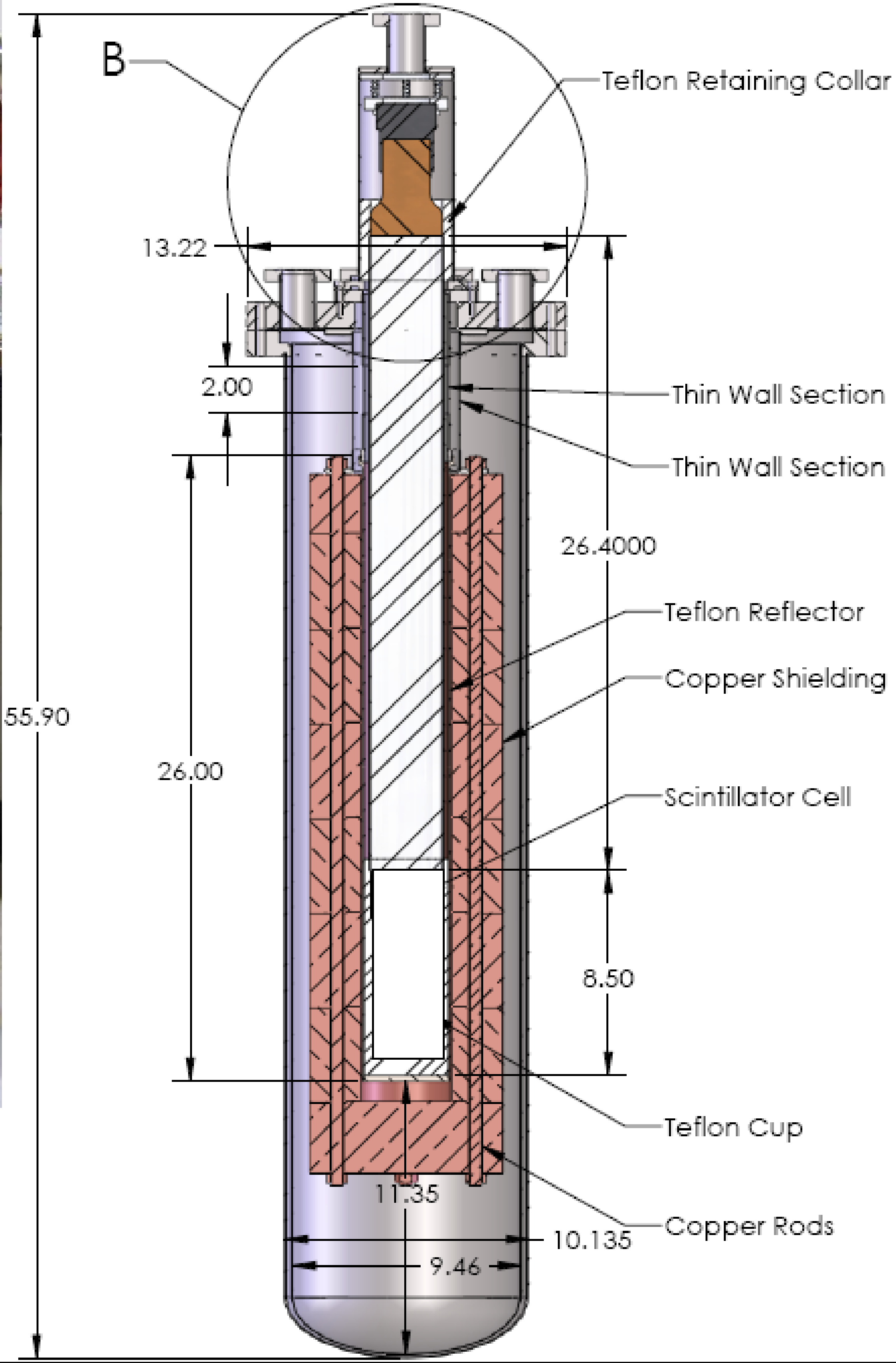
Ar mass: LAr ~0.7kg

High Crystallize Teflon Cup

WLS: TPB/PTP

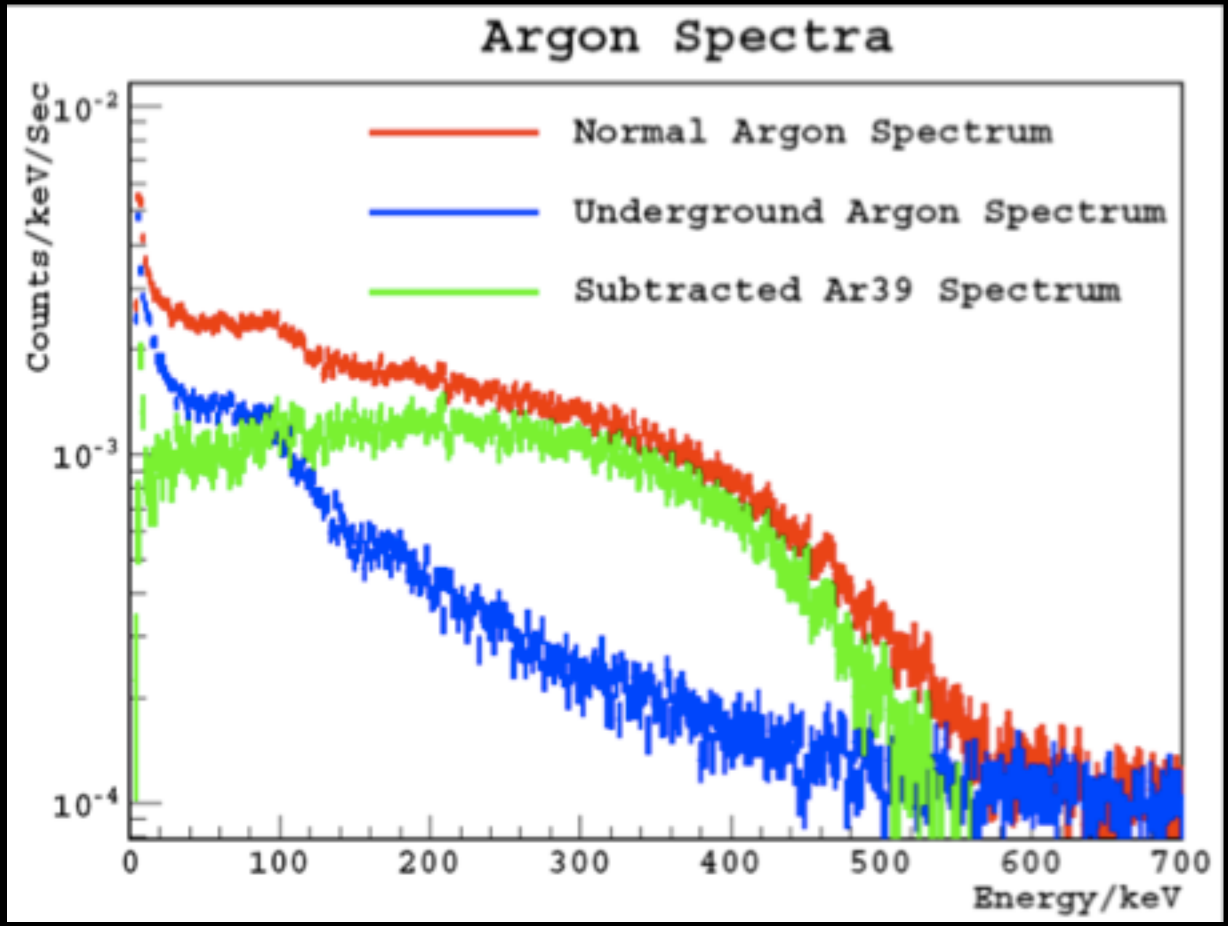
PMT R11065, No Light Guide

Kimballton Mine (~1500m.w.e)



Underground Argon

- Kinder Morgan Doe Canyon complex (Cortez, CO)
  - Ar ~400 ppm in underground gas
- ^{39}Ar level: factor 25 reduction or greater
- Total Ar production capacity: 3 tons per day

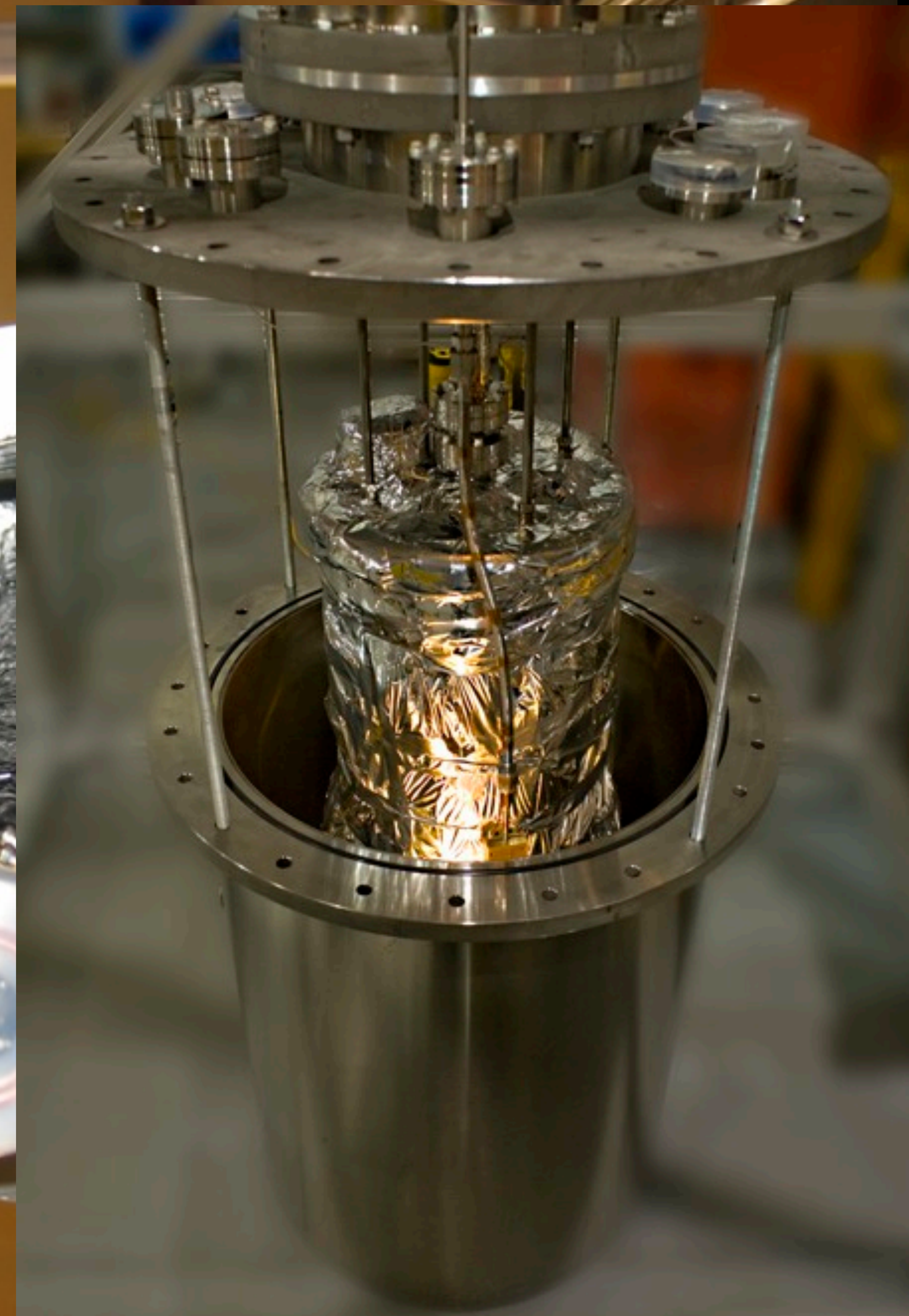


Princeton Prototype Plant for Industrial Scale Production: Achieved 0.5 kg/day (depletion >25)

News: NSF funding (NSF PHY-0811186), goal ~10 kg/day in 2010

Princeton Prototype Cryogenic Distillation Column @ FNAL PAB

Princeton Prototype Cryogenic Distillation Column @ FNAL PAB



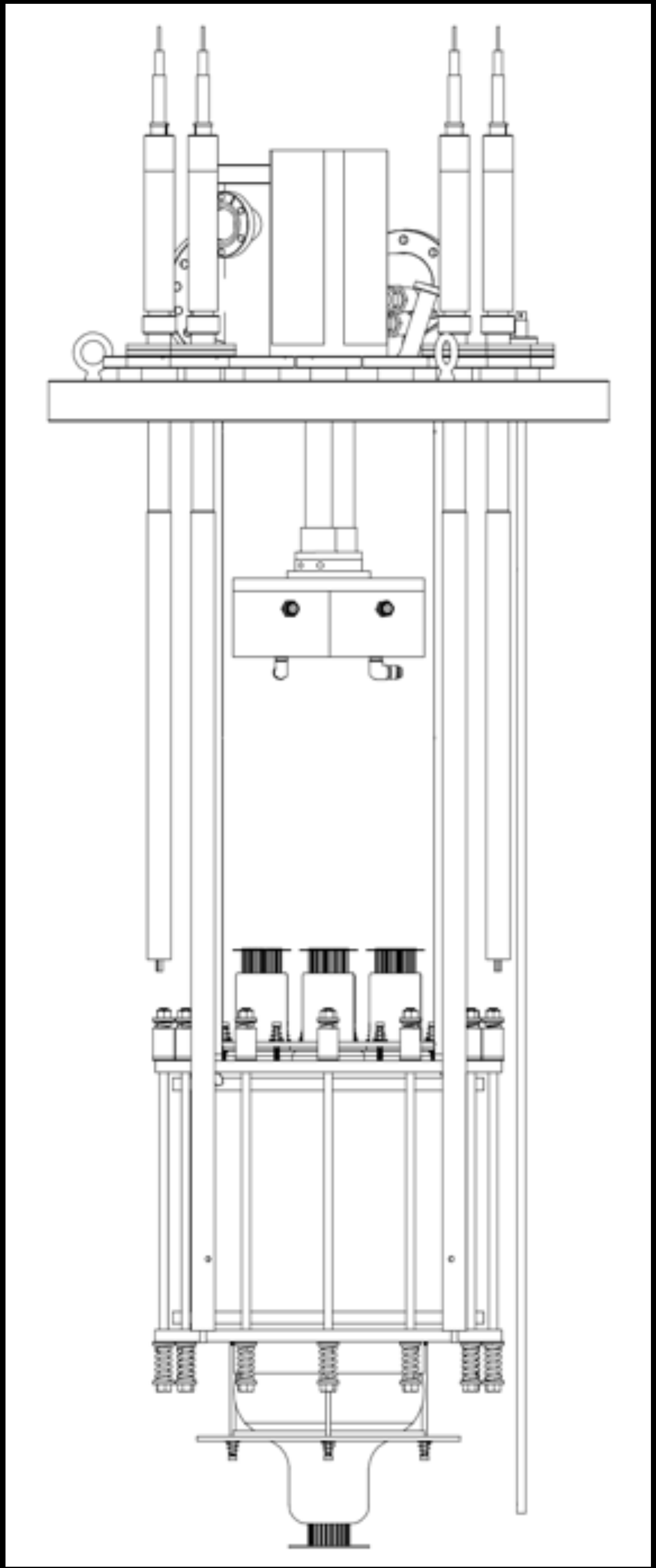
Backgrounds

Detector Element	Electron Recoil Backgrounds		Radiogenic Neutron Recoil Backgrounds		Cosmogenic Neutron Recoil Backgrounds	
	Raw	After Cuts	Raw	After Cuts	Raw	After Cuts
^{39}Ar	2.5×10^{7}	$<1\times10^{-2}$	–	–	–	–
Fused Silica	3.6×10^{5}	1.4×10^{-4}	1.8	4.5×10^{-3}	2.3	1.4×10^{-4}
PTFE	306	1.2×10^{-7}	0.024	6.0×10^{-5}	0.17	1.0×10^{-5}
Copper	2,146	8.6×10^{-7}	0.0024	6.0×10^{-6}	0.72	4.3×10^{-5}
QUPIDs	7.0×10^{4}	2.8×10^{-5}	0.31	7.8×10^{-4}	0.34	2.0×10^{-5}
R11065 PMTs	2.6×10^{6}	1.0×10^{-3}	19.4	4.9×10^{-2}	0.34	2.0×10^{-5}
Titanium	2.4×10^{4}	9.6×10^{-6}	1.1	2.8×10^{-3}	13	7.7×10^{-4}
Veto Scintillator	70	2.8×10^{-8}	0.030	7.5×10^{-5}	26	0.0015
Veto PMTs	2.5×10^{6}	1.0×10^{-3}	0.023	5.7×10^{-5}	–	–
Veto tank	1.7×10^{5}	6.8×10^{-5}	6.7×10^{-5}	1.7×10^{-7}	19	0.0076
Water	6,100	2.4×10^{-6}	6.7×10^{-4}	1.7×10^{-6}	19	0.0076
CTF tank	8,300	3.3×10^{-6}	3.5×10^{-3}	8.7×10^{-6}	0.068	2.7×10^{-5}
LNGS Rock	920	3.7×10^{-7}	0.061	1.5×10^{-4}	0.31	0.012
Total	–	1.1×10^{-2} (1.2×10^{-2})	–	0.0082 (0.056)	–	0.030 (0.030)

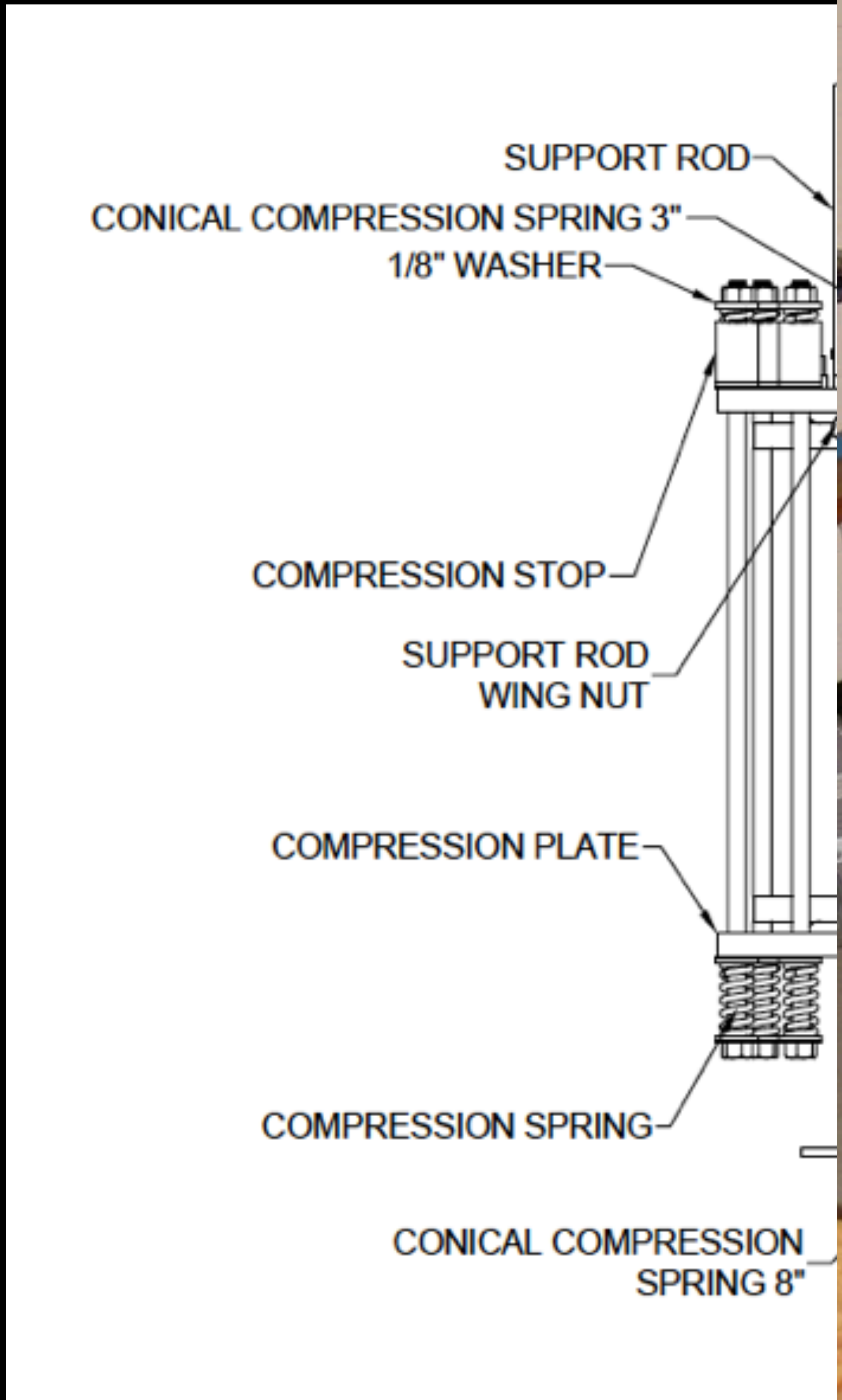
TABLE I: A summary of the expected electron- and neutron-recoil backgrounds in 0.1 ton-yr of data from DarkSide-50 before and after applying the background rejection cuts described in the text (all units are events/(0.1 ton-yr)). The ^{39}Ar rates are given for the gas collected at Cortez (depletion factor of 25 or more). The "Total" row assumes the configuration with QUPIDs (numbers in parenthesis apply to the initial configuration with R11065 PMTs). Note that the majority of the entries in this Table are based on limits on, rather than measurements of, the radioactive contaminants in the different detector component materials.

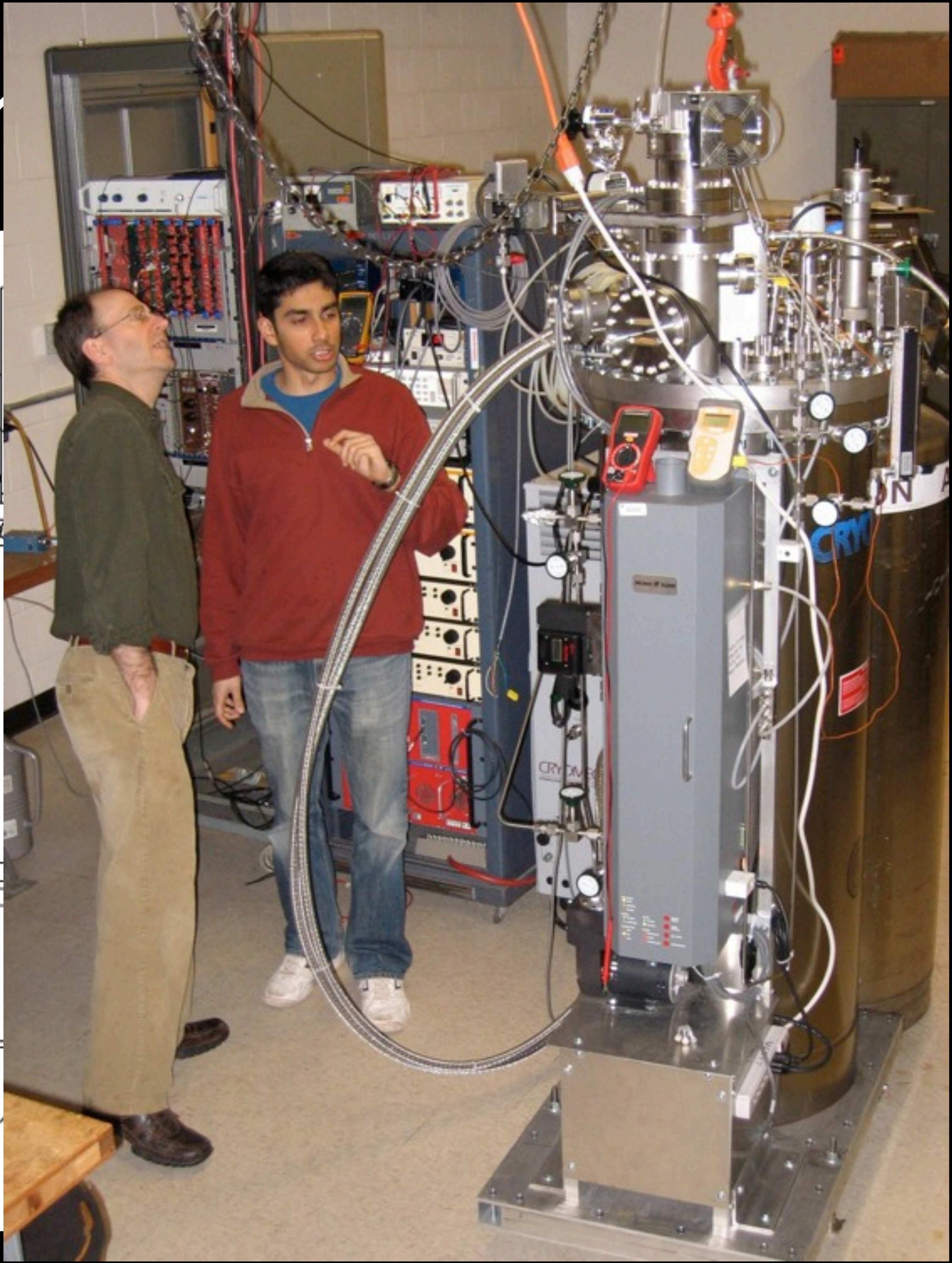
DarkSide-10 Prototype

- A (relatively) simple and (relatively) fast turn-around full-featured 2-phase TPC
- A testbed for learning the technology and testing features to use on later detectors
- Partially-sealed transparent inner vessel
- High light-yield design
- Transparent conducting windows for anode and cathode
- Submerged low-background, high-QE Hamamatsu R11065 3" PMTs
- Demonstrate gas pocket control for 2-phased operation
- α source deployment to study surface background

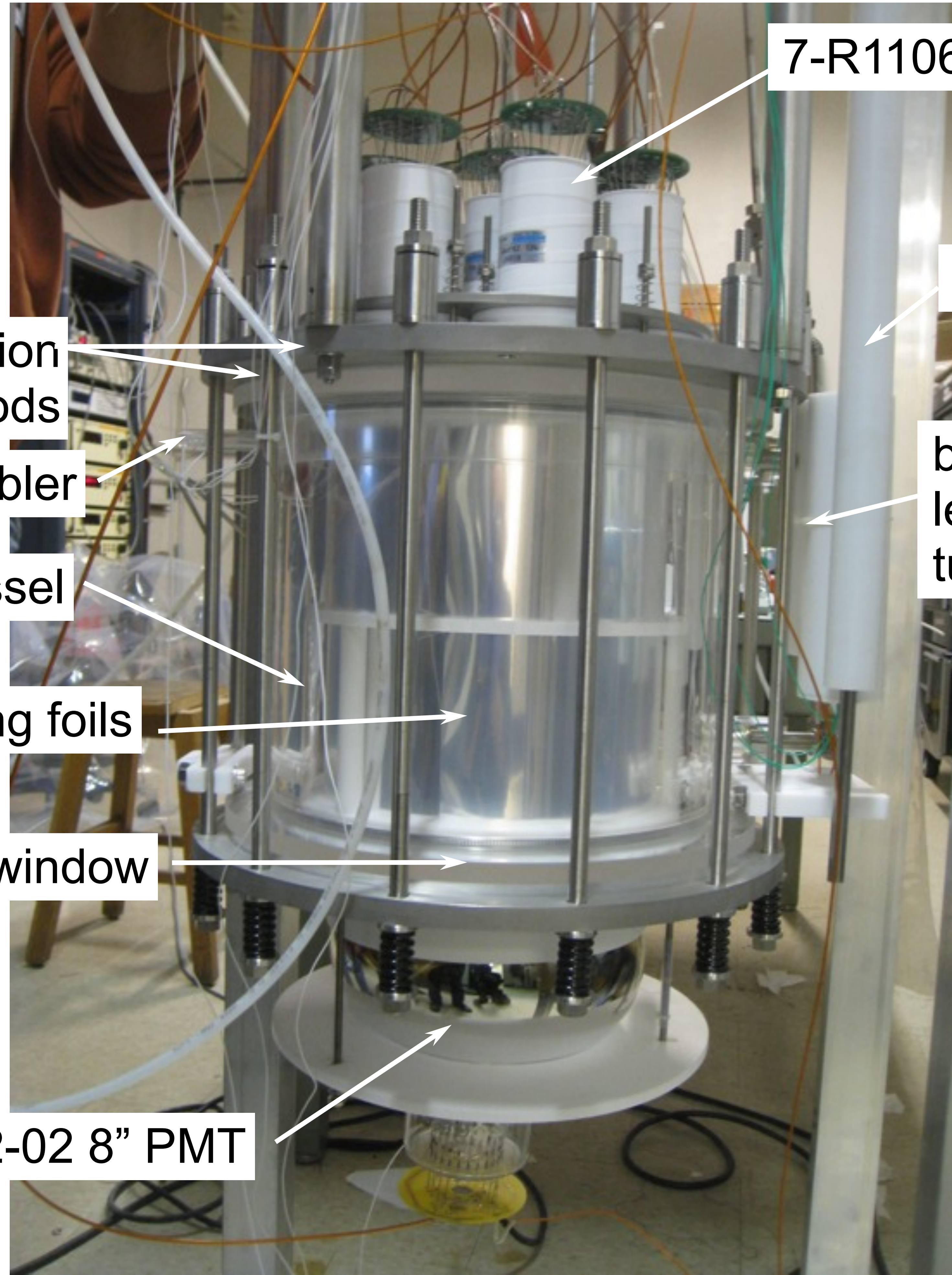


10-kg 2-Ph

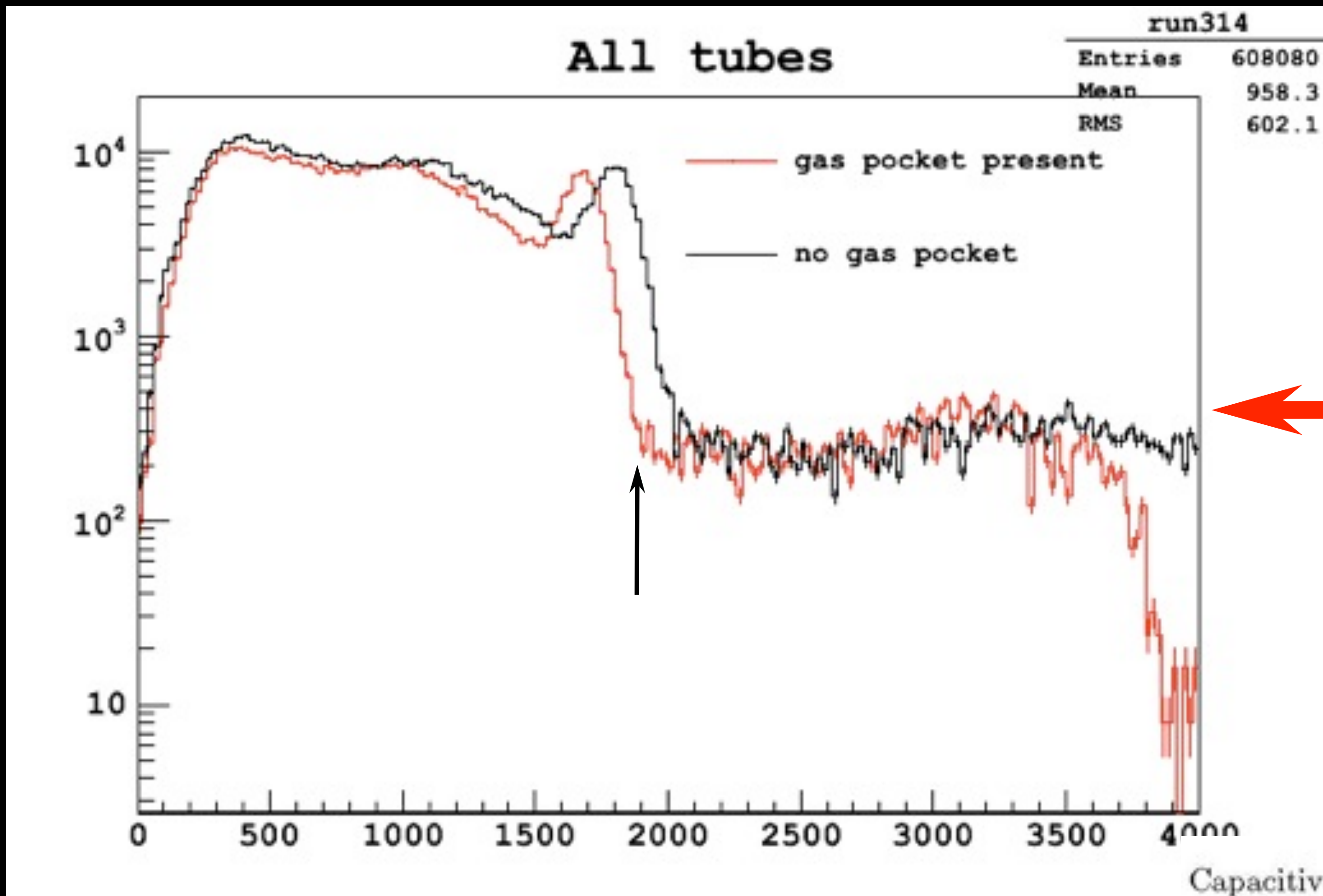

SUPPORT ROD
CONICAL COMPRESSION SPRING 3"
1/8" WASHER
COMPRESSION STOP
SUPPORT ROD
WING NUT
COMPRESSION PLATE
COMPRESSION SPRING
CONICAL COMPRESSION
SPRING 8"



First deployment
March-July 2010
Scintillation-only,
no field cage



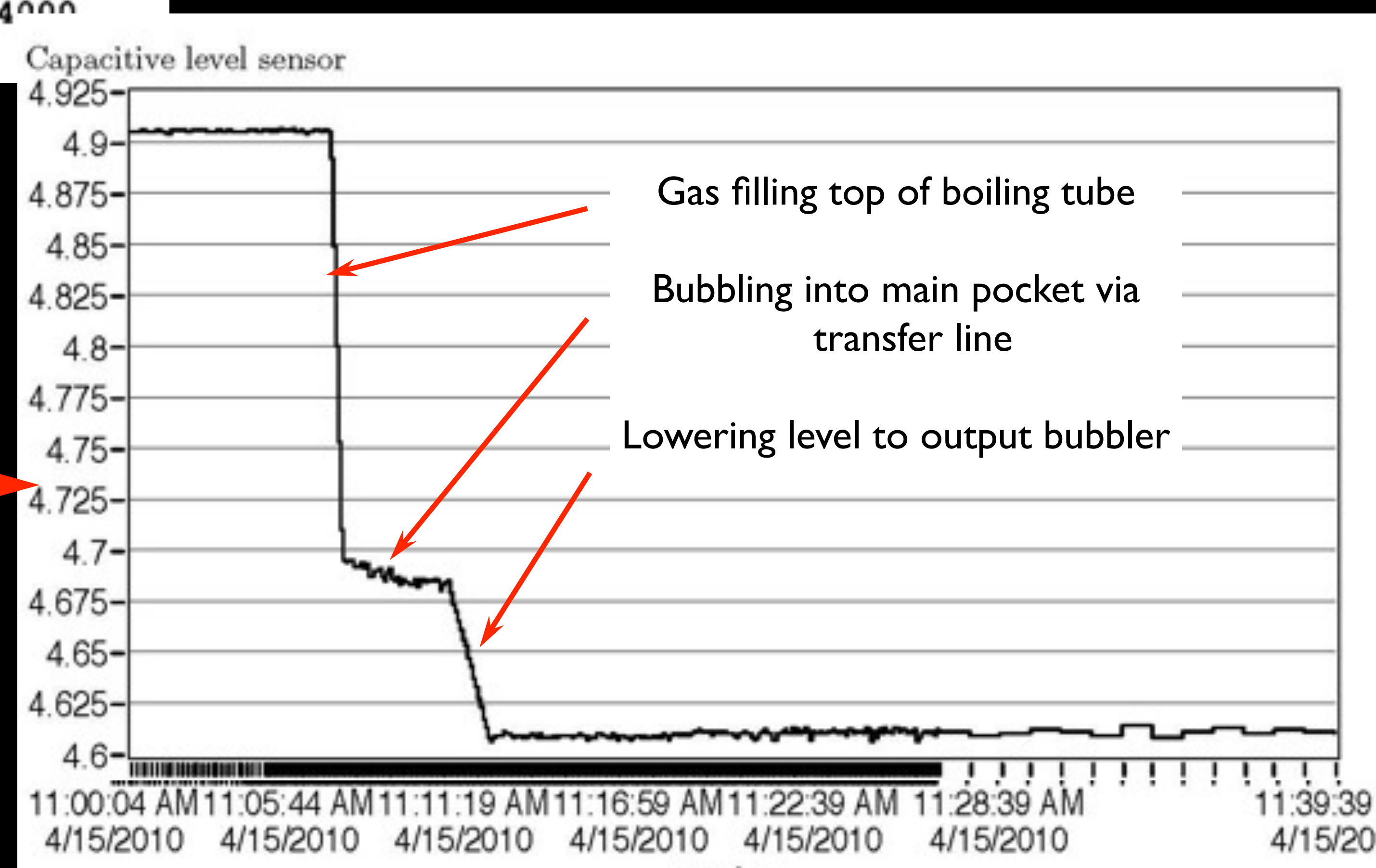
First Deployment Results



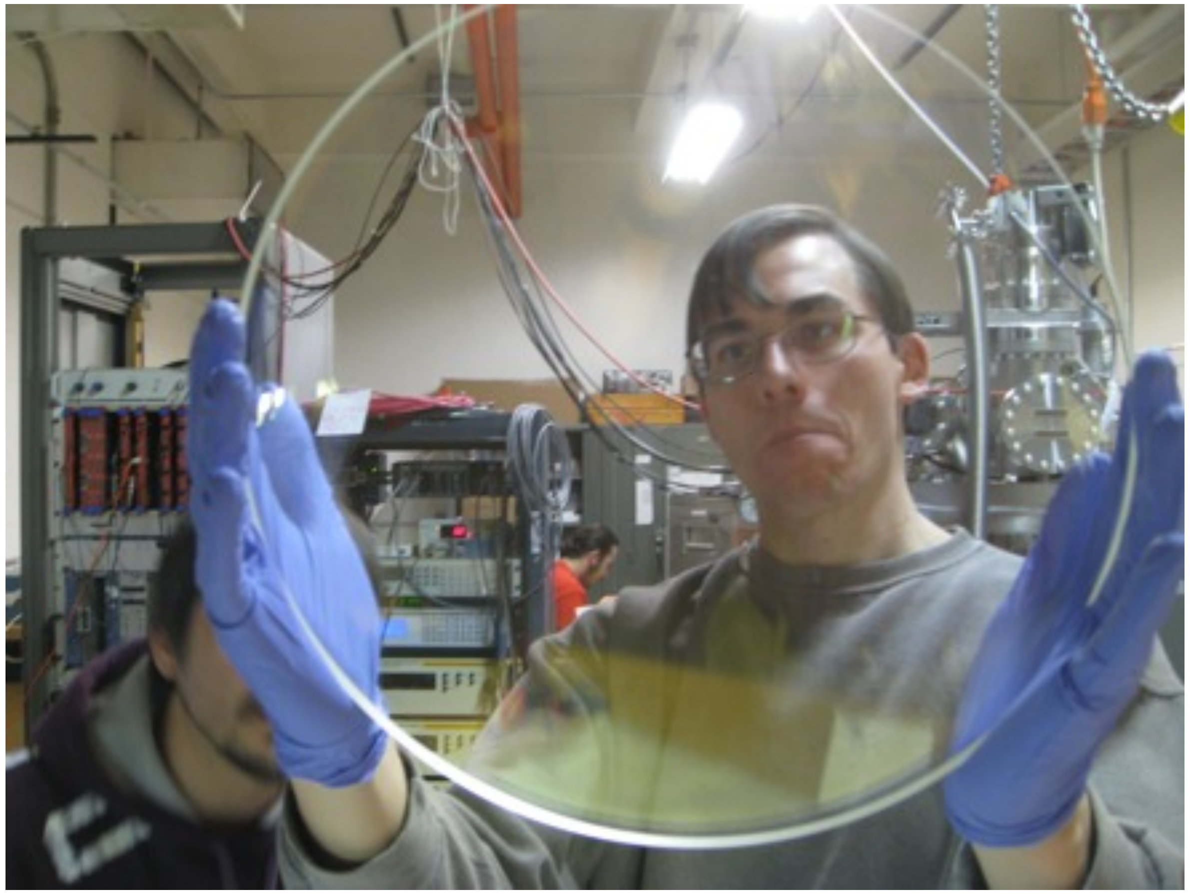
Light-yield from ^{22}Na spectrum in coincidence with external NaI counter. From 511 keV line, estimate 4-5 p.e./keV$_{ee}$

Small change (-6%) in double phase configuration

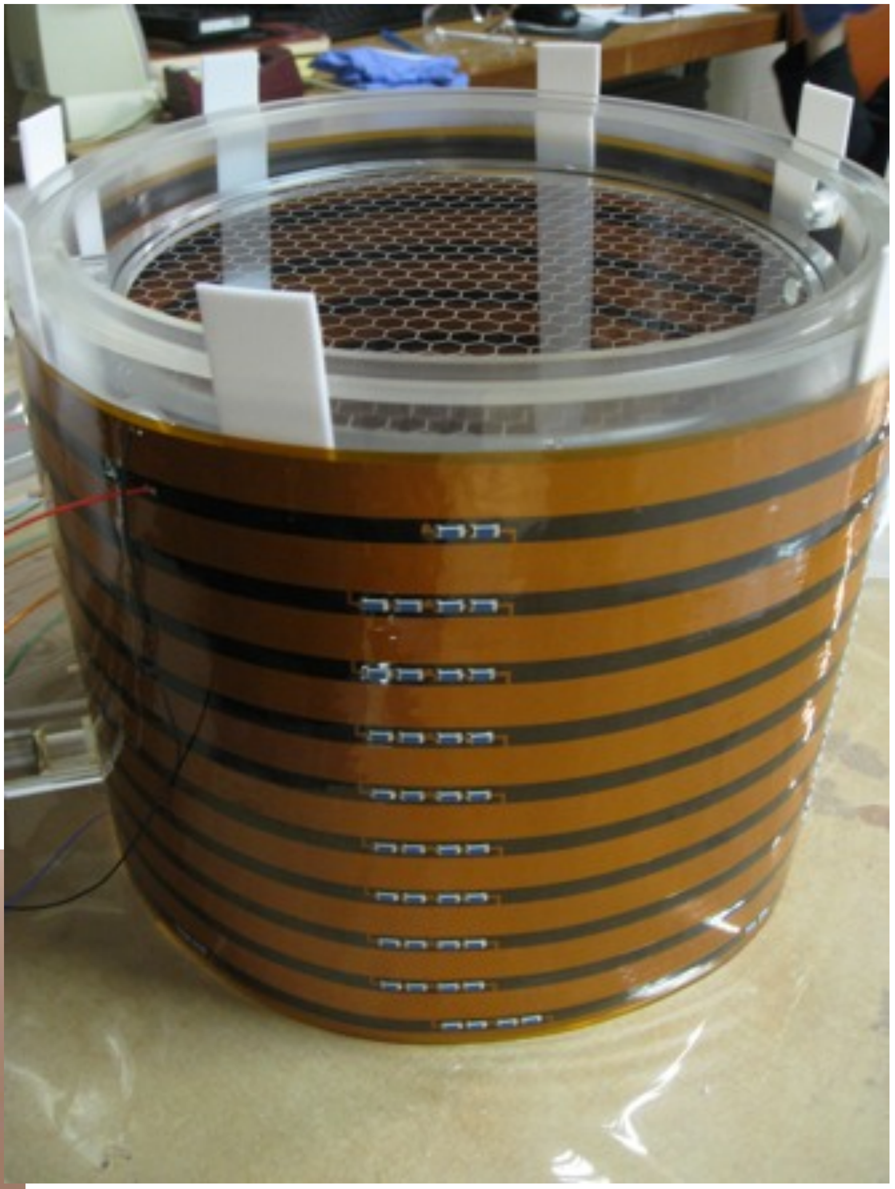
Create, monitor, and maintain gas pocket for 2-phase TPC



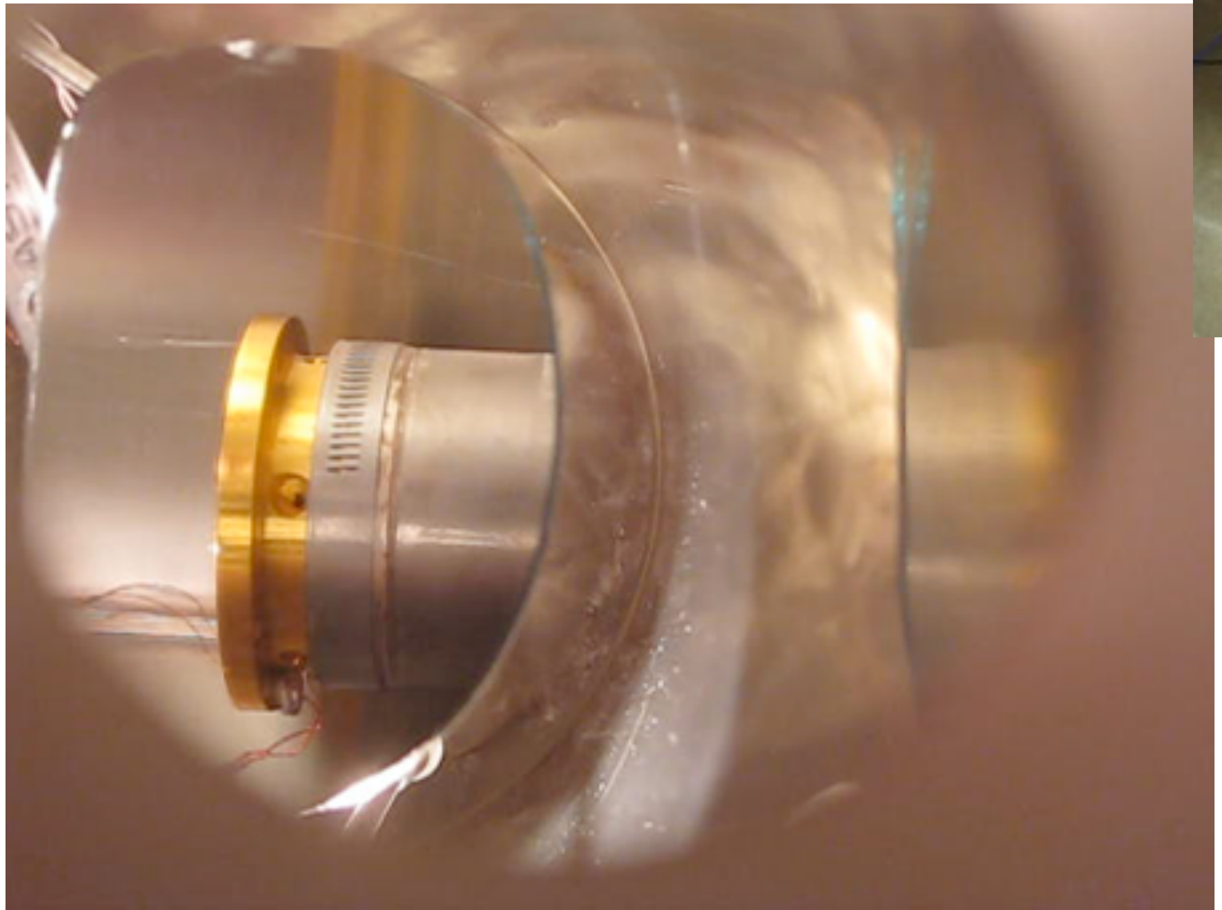
Second deployment – October 2010



ITO-coated acrylic cathode window

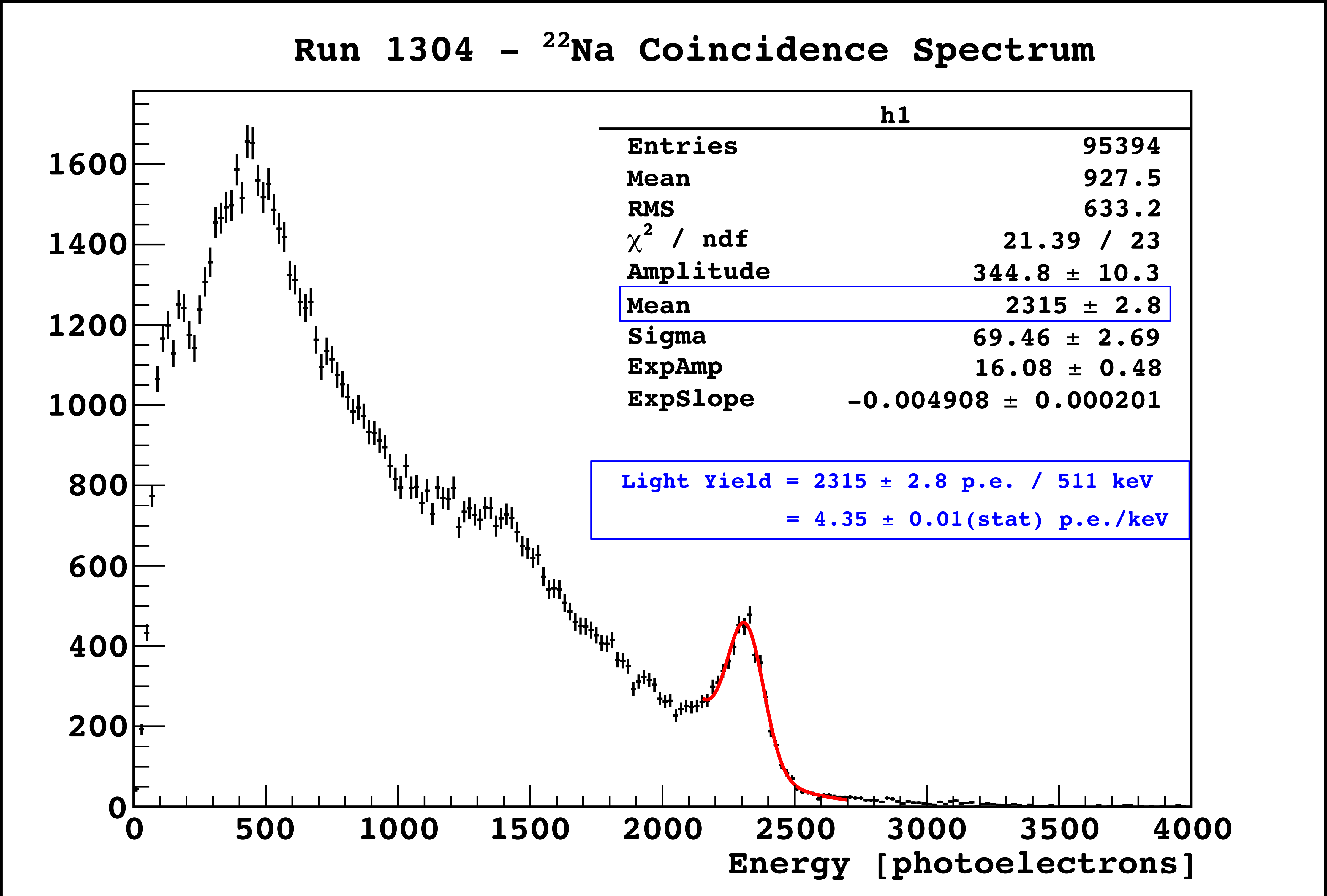


Field cage flexPCB, etched extraction grid

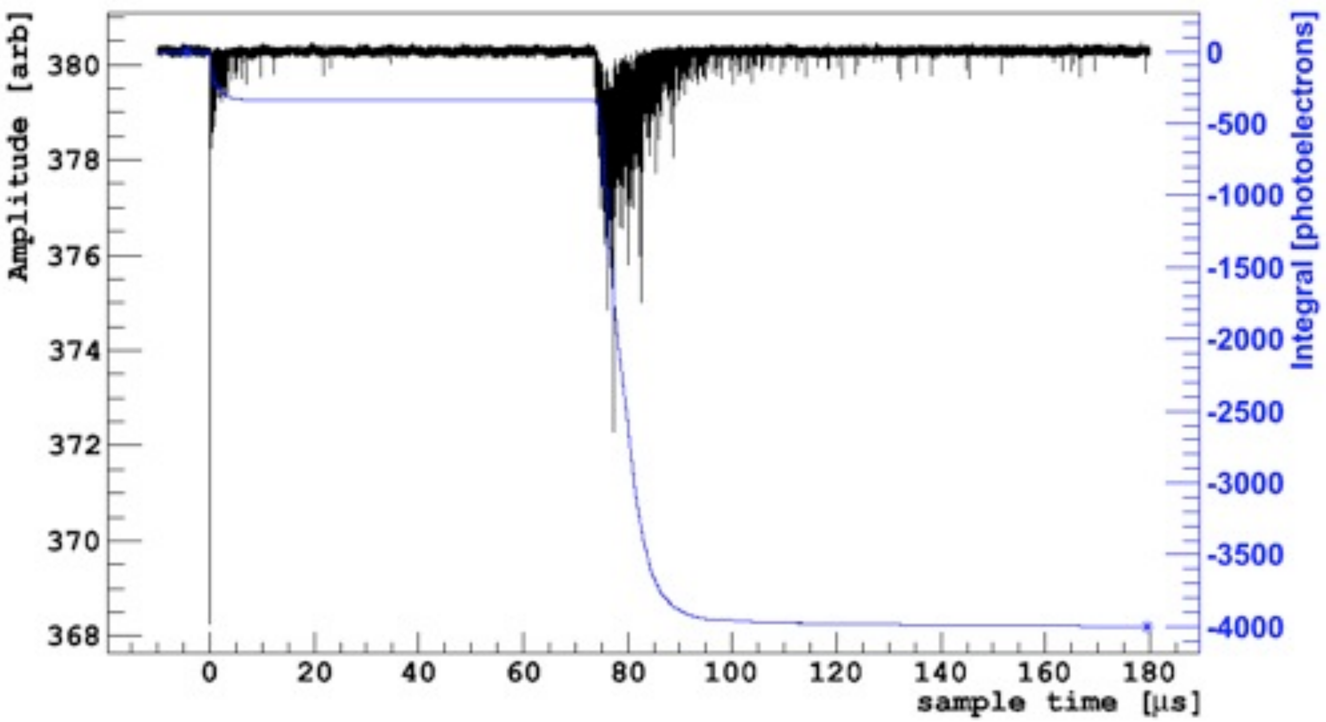


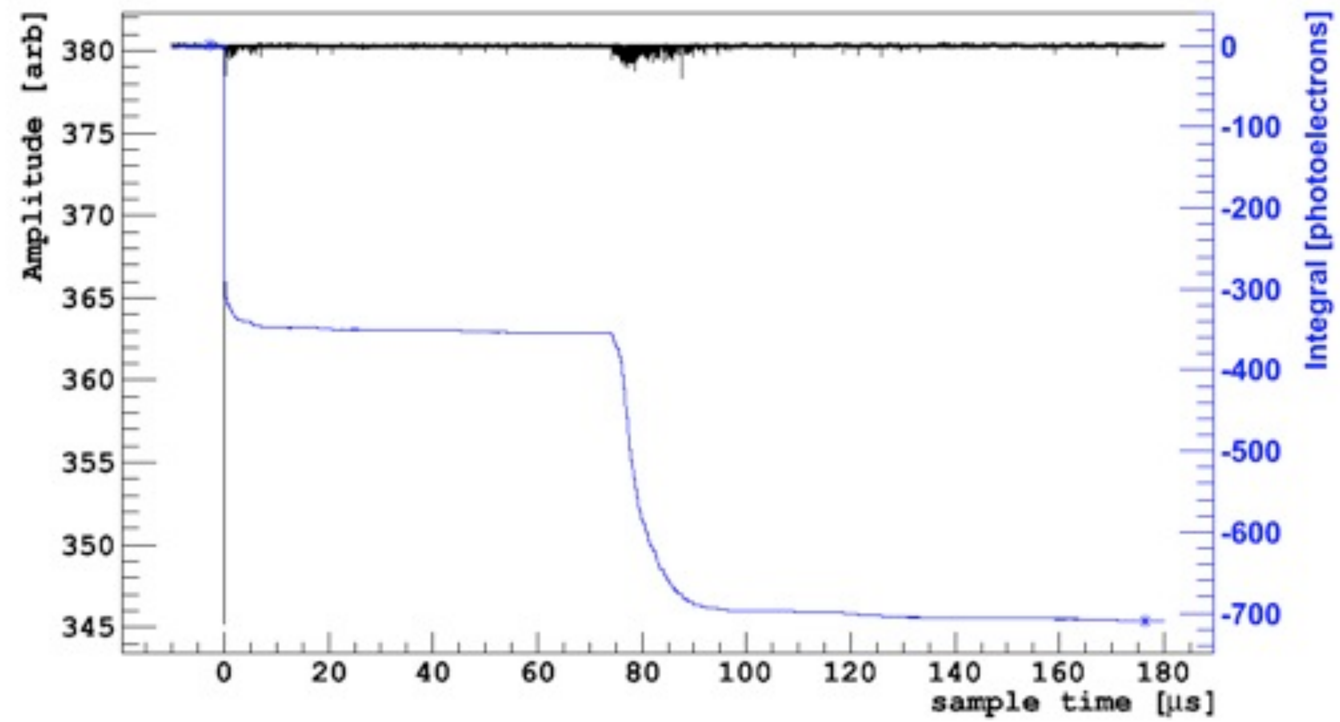
LN2-powered coldhead (movie!)

DarkSide-10 Results



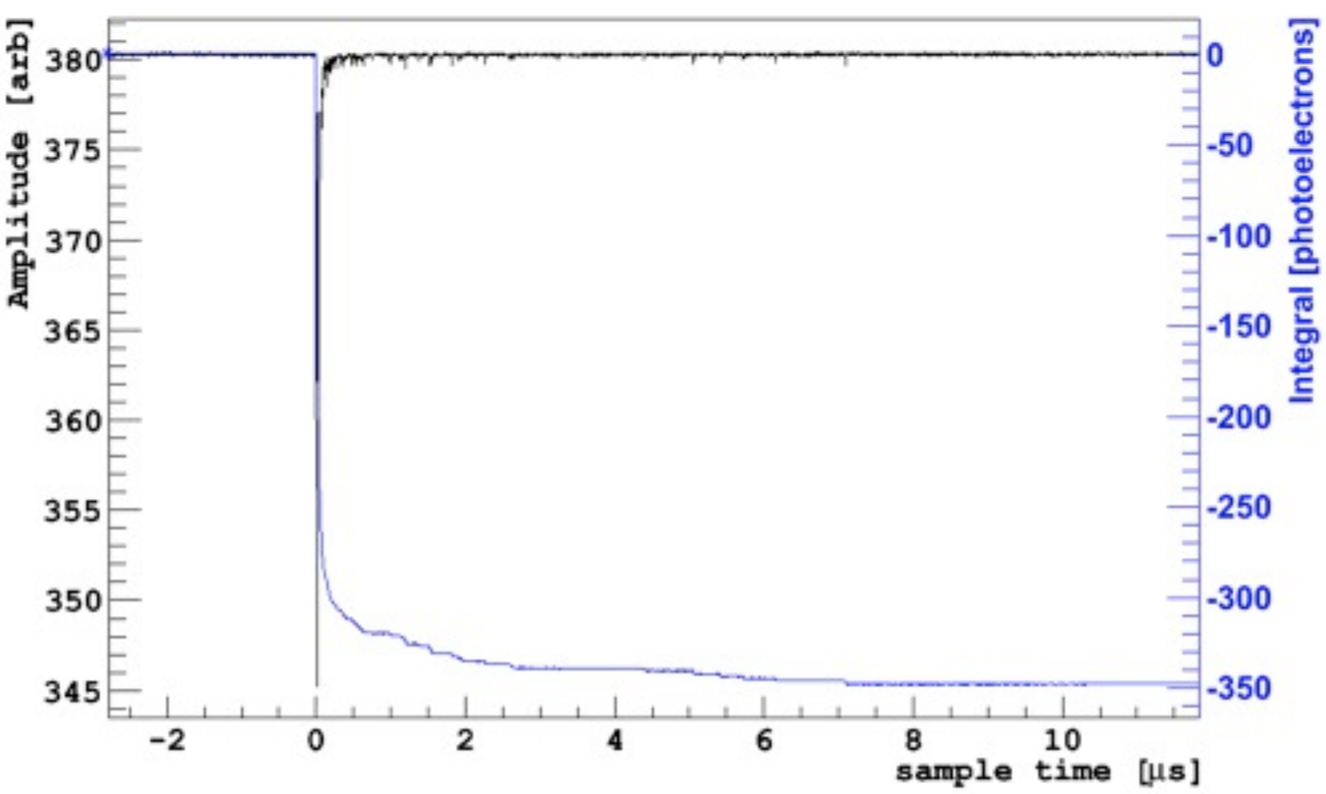
DarkSide-10 Results

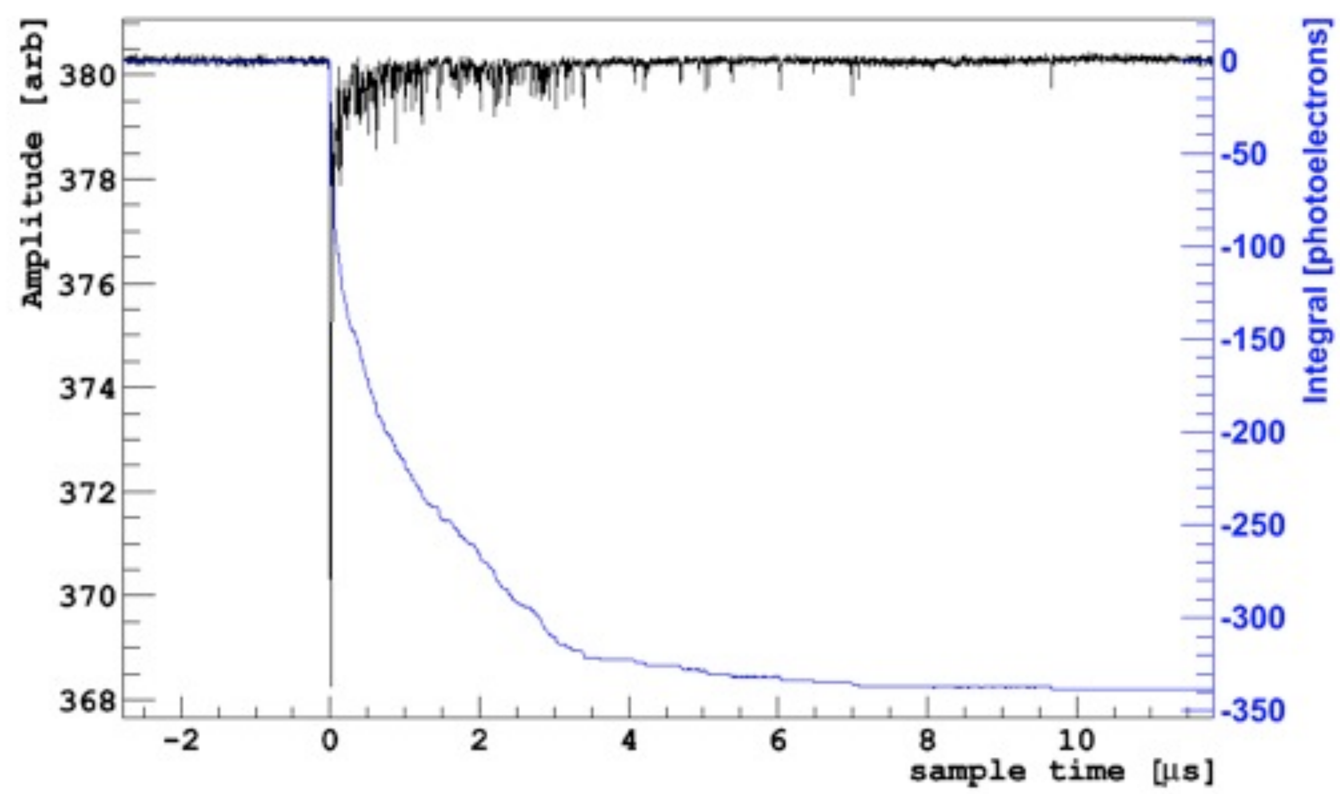




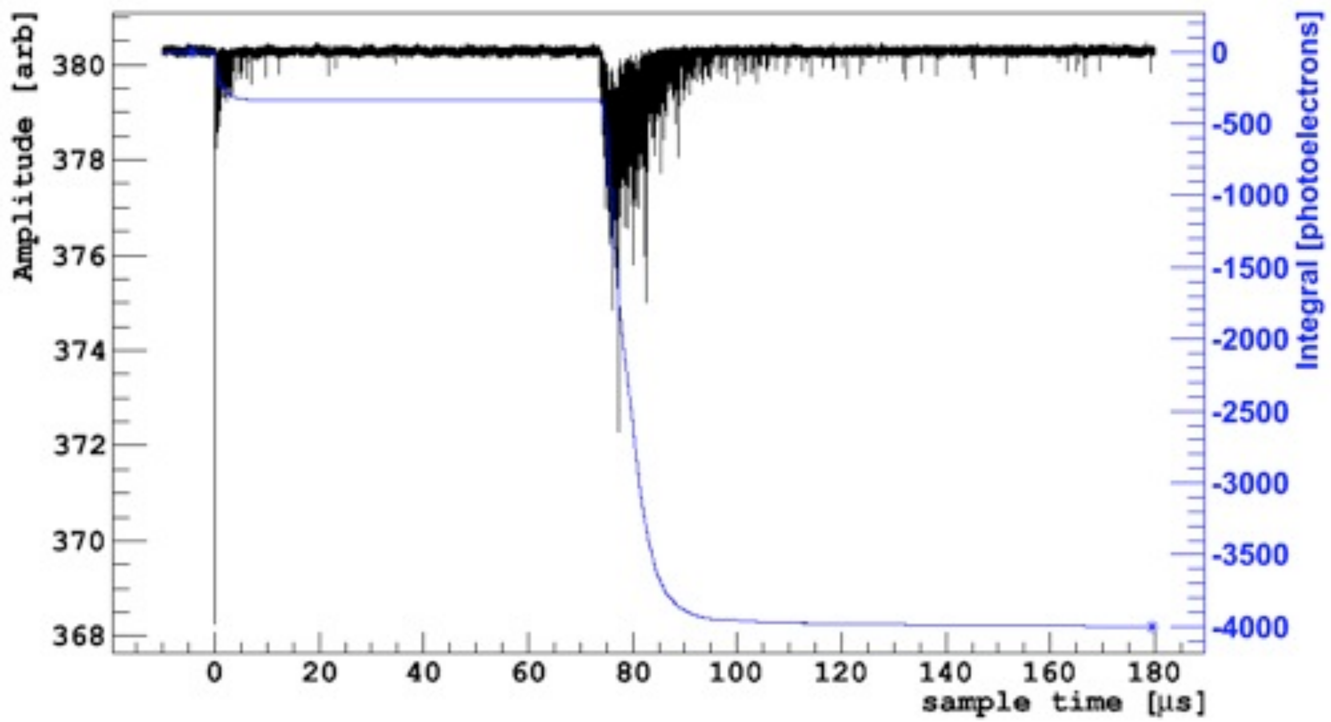
Beta/Gamma

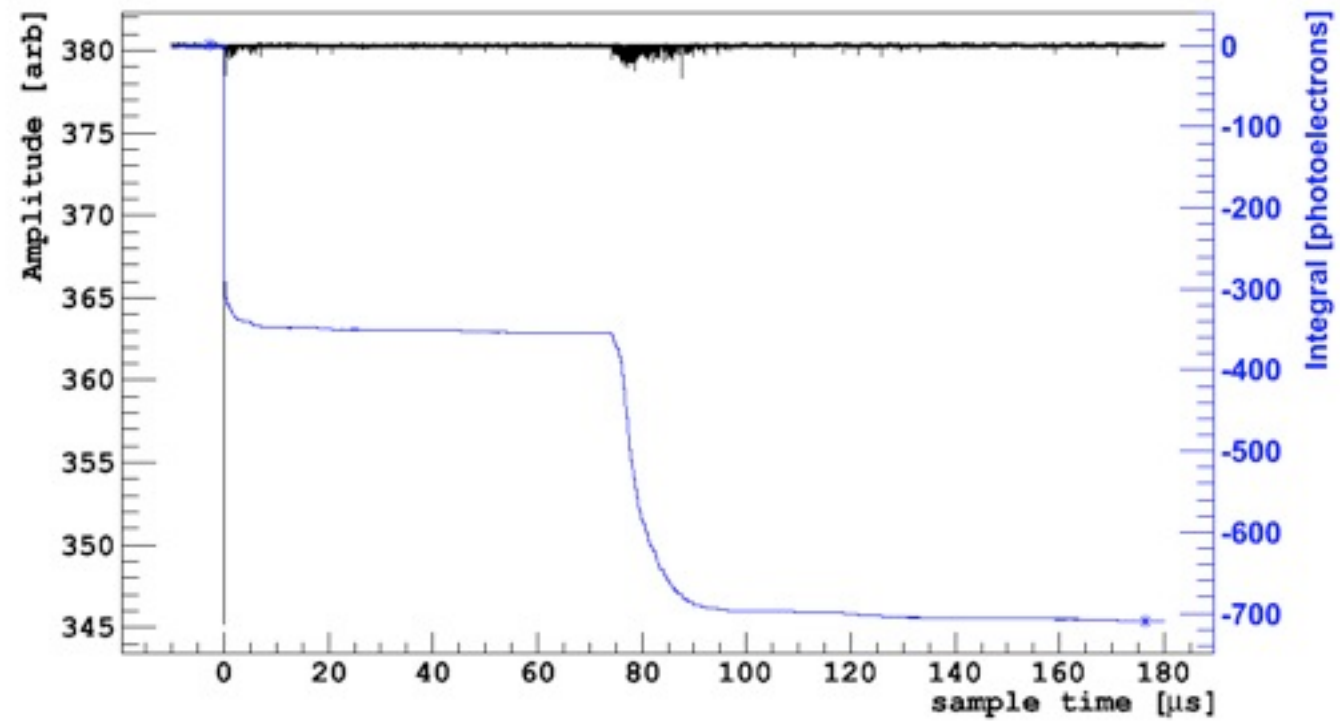
Nuclear Recoil





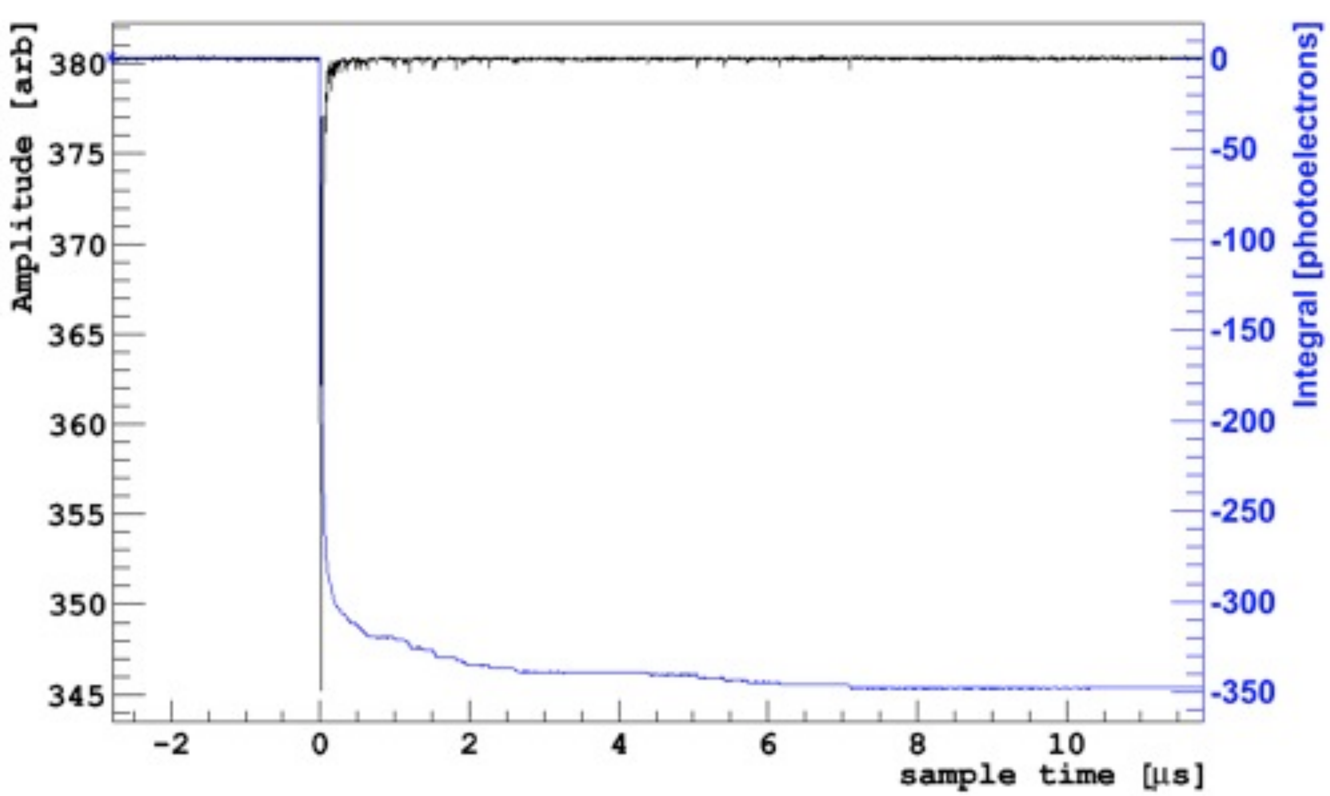
DarkSide-10 Results

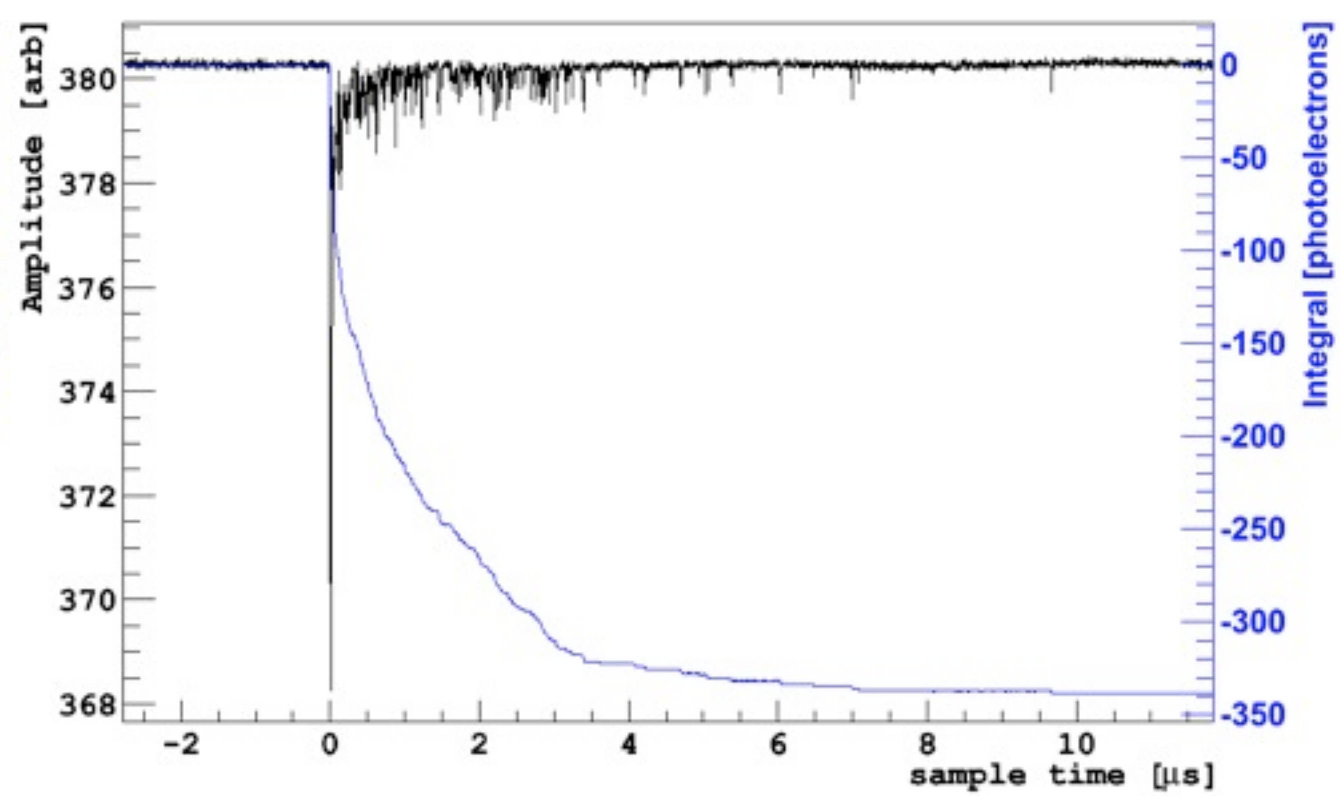




Beta/Gamma

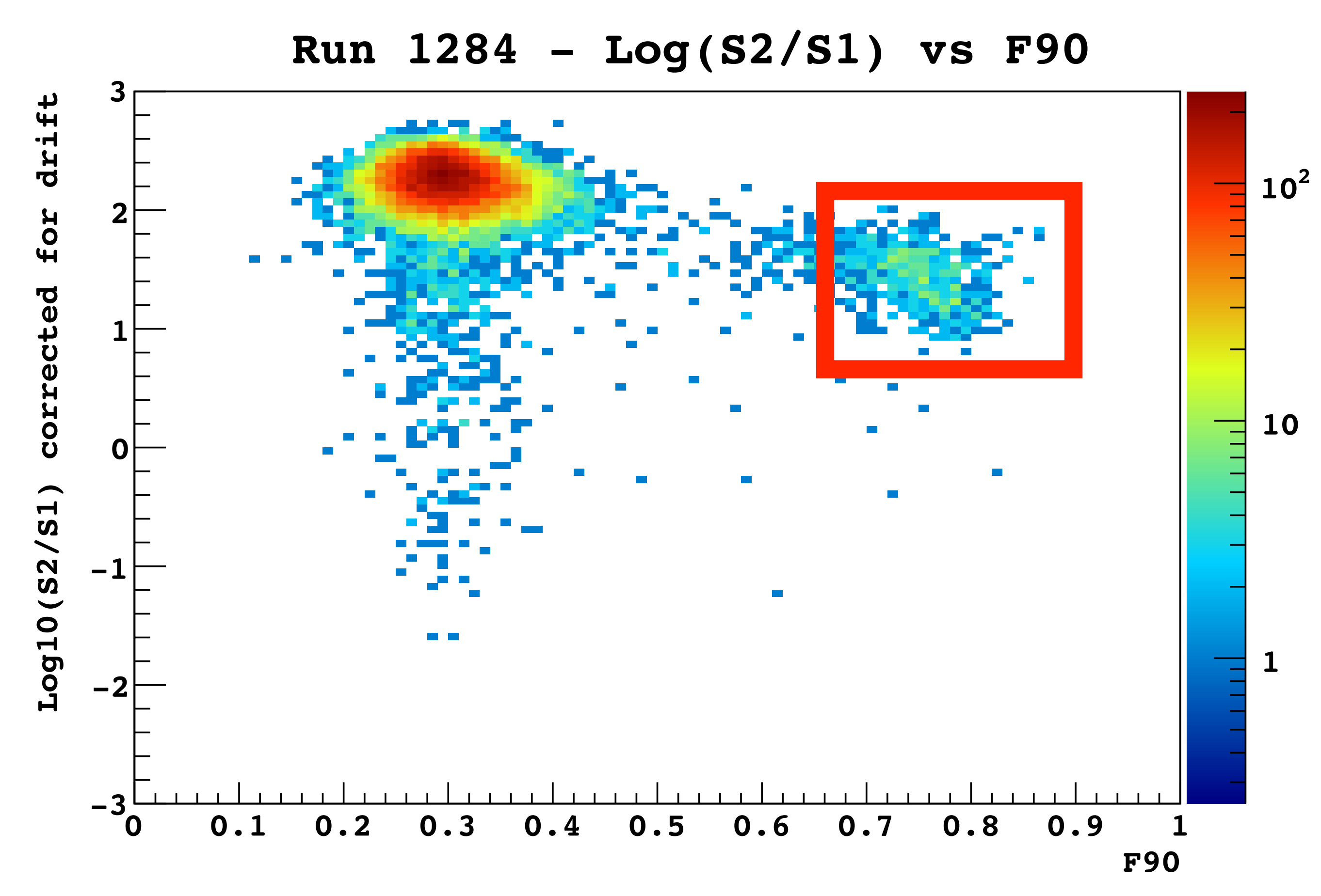
Nuclear Recoil



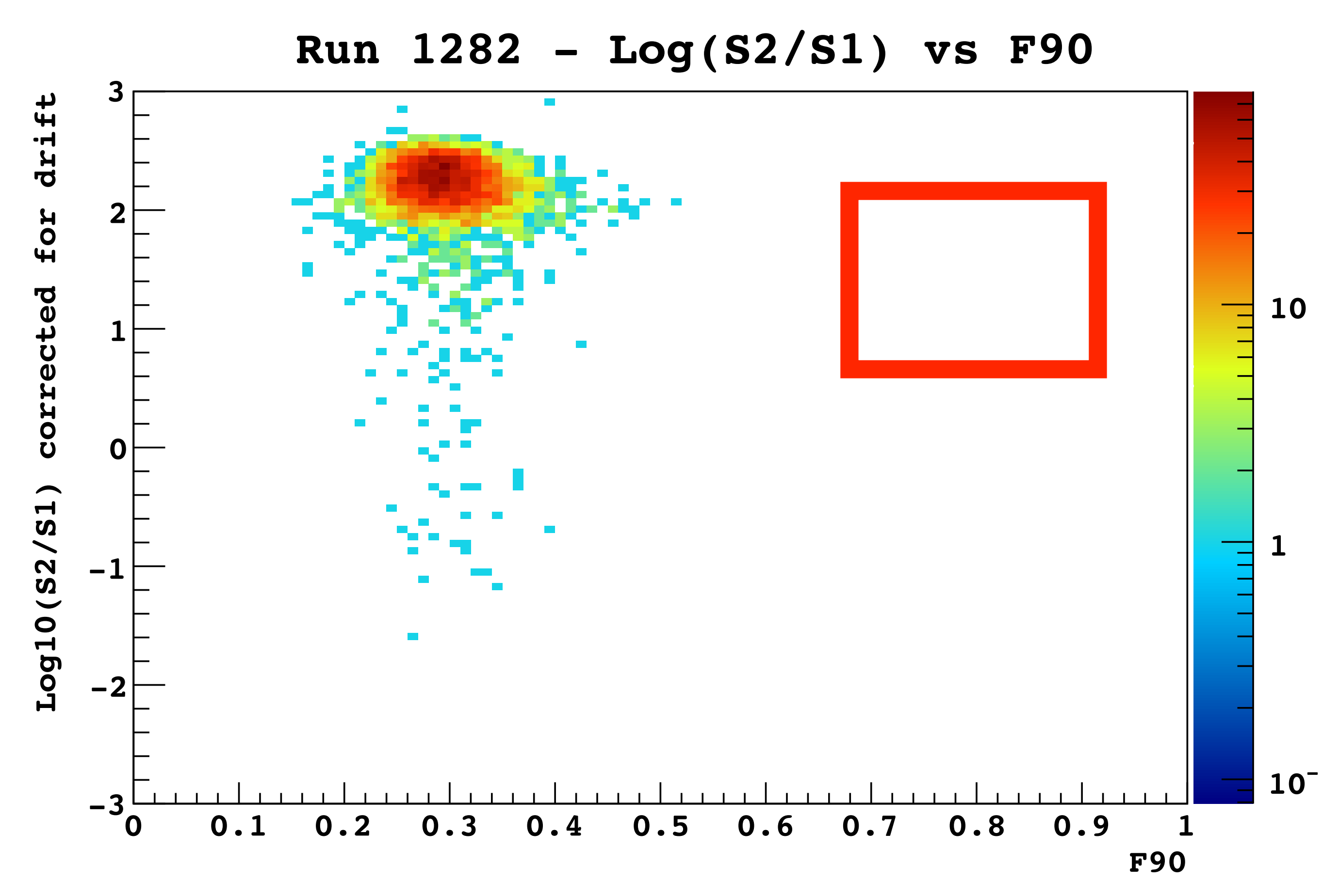


DarkSide-10 Results

AmBe Source

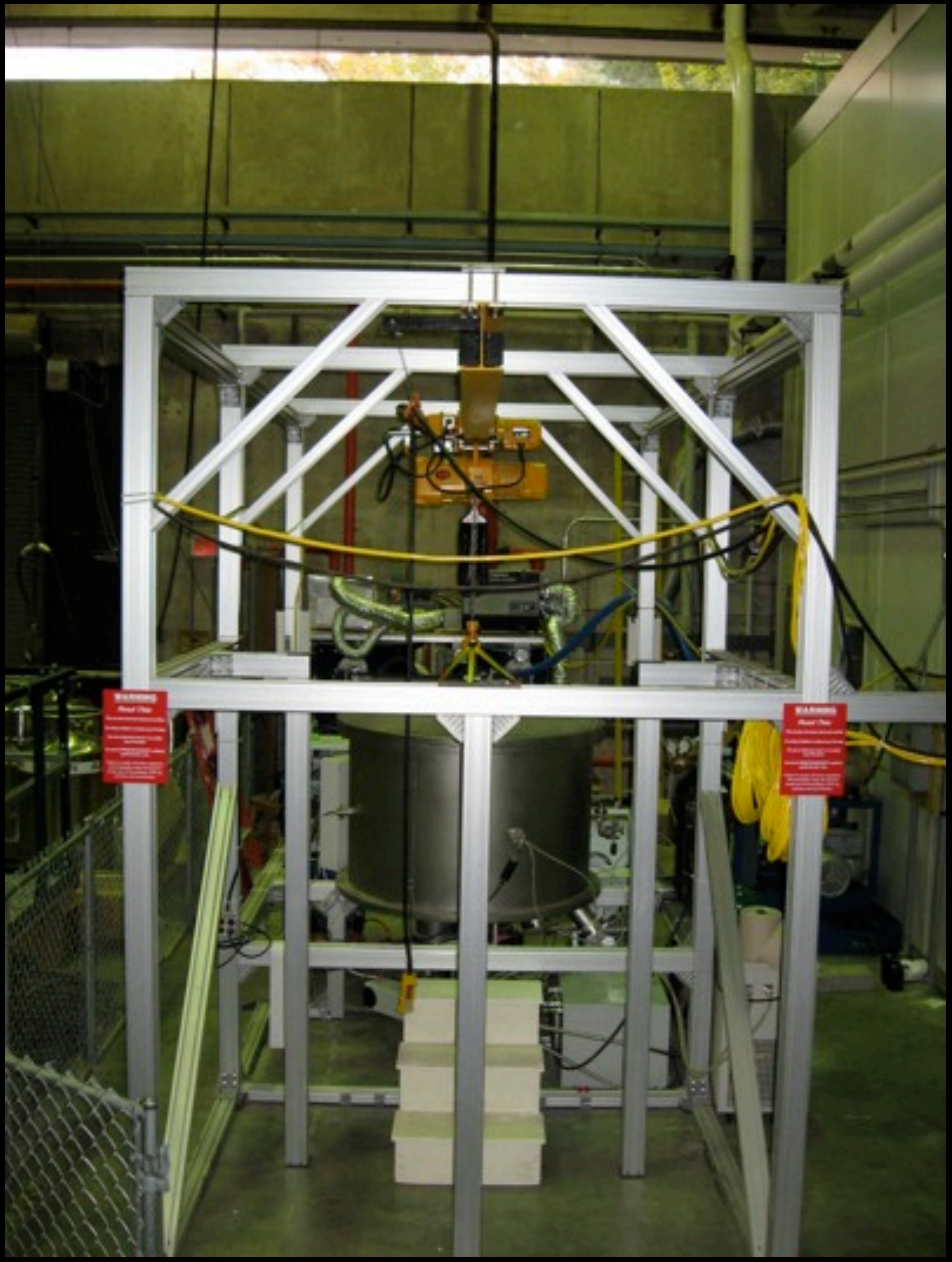


No AmBe Source



Rn-Free Clean Room

Evaporator & Test Unit



Funding - USA

- The NSF funded the proposal submitted by the US groups for DarkSide-50 in September 2010, awarding Grant NSF PHY-1004072 ($875k for FY2010), with the bulk of funds for FY2010 to be spent primarily on the refurbishment of the CTF under the new CTF-RD program
  - Institutions awarded: Augustana, Houston, Princeton, Temple, UCLA, UMass Amherst
- Collection of depleted argon target independently funded by NSF Grant PHY-0811186 to Princeton University ($1.7M for FY2010-11)
- R&D Grants NSF PHY-0919363 ($3.5M), PHY-0704220 ($1.9M)
- Cavity Ring-Down Spectroscopy trace gas analyzers for the measurement of ultra-trace contaminations of O_2, N_2, and H_2O in development at and at Black Hills State University supported by Grants NSF PHY-0903335 and NSF MRI-0923557
- Final purification of the depleted argon at Fermilab, with cryogenic distillation column procured by the Princeton group with funding from NSF Grant PHY-0811186
- DarkSide-50 received stage 1 approval as project E-1000 from the Fermilab directorate in January 2010

Funding - Italy

- In September 2010 INFN approved the proposal for CTF-RD and allocated €100,000 in FY2011 for the borated scintillator and for a portion of the photosensors for the neutron and muon vetoes.

- Additionally, €160,000 allocated as part of the Borexino FY2011 funding for the upgrade of the electronics of CTF-RD, under the acknowledgment that the electronics of CTF-RD will serve as a prototype for a future upgrade of the Borexino electronics.

DS-10 and DS-50 Schedule

- DS-10
  - Summer 2011
- DS-50 ID
  - End of 2011
- Neutron Veto
  - Summer 2012

The DarkSide Program

- DS-10
  - 2011
- DS-50
  - 2012
- Ton-Scale Detector: DS-1k
  - 2014
- Ten-ton Scale Detector: DS-20k (DS-50k?)
  - 2017-9
  - Requires much deeper Lab. Jinping?

Cooperation w IHEP

- Science
- Technology
- Low Background
- Training
- Development Underground Lab Space

Like the jelly beans in this jar, the Universe is mostly dark: 96 percent consists of dark energy (about 70%) and dark matter (about 26%). Only about four percent (the same proportion as the lightly colored jelly beans) of the Universe - including the stars, planets and us - is made of familiar atomic matter.

The End